

Bulletin 15

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

INVESTIGATIONS OF EXPLOSIVES
USED IN COAL MINES

BY

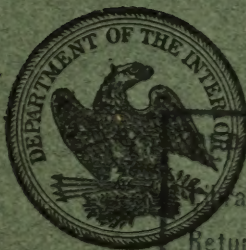
CLARENCE HALL, W. O. SNELLING, AND S. P. HOWELL

WITH A CHAPTER ON THE NATURAL GAS USED AT PITTSBURGH BY

G. A. BURRELL

AND AN INTRODUCTION BY

CHARLES E. MUNROE



DEPARTMENT OF MINING ENGINEERING

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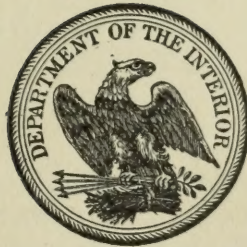
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INVESTIGATIONS OF EXPLOSIVES USED IN COAL MINES.

By CLARENCE HALL, W. O. SNELLING, and S. P. HOWELL.

INTRODUCTION.

By CHARLES E. MUNROE.

The explosives used in coal mines not only occasion accidents such as occur in the use of explosives elsewhere, but they frequently cause widespread disasters by igniting explosive mixtures of mine gas and air and of coal dust and air, or both. In addition, the firing of explosives so shakes the walls and roofs of the mines as to cause falls, with their attendant casualties.

Considering the large number of explosives and their wide range in composition and properties, it is obvious that certain of them should prove more suitable for use in coal mines than others. The problem is to determine which explosives are the most suitable for this purpose and the precise conditions under which they may be used with the greatest safety.

Of course this problem could be worked out in actual mining, but experimental investigations when accompanying commercial operations are hazardous and slow. To obtain the information sought, in the speediest and most economical manner, laboratory methods must be resorted to. The adoption of such methods began about 30 years ago with experiments in an iron gallery mounted on wheels, at Zwickau, Germany. This laboratory method of attacking the problem has so commended itself that it has not only been repeated elsewhere in Germany but has at intervals been officially adopted, with many modifications and additions, by the Governments of Belgium, Austria, France, and Great Britain.

Such was the status of coal-mine investigations in Europe when in 1904, an organization in the Geological Survey, which in 1907 became the technologic branch, was created to investigate the mineral-fuel resources of this country. At that time no division of the National Government had official cognizance of conditions existing in our mines, but through its system of collecting fuels for tests the technologic branch was forced to recognize that coal-mine accidents are a factor that must be reckoned with in determining the extent and availability of our mineral-fuel resources. This became so

apparent, and it was so obviously a function of this branch to make a systematic research as to the cause and prevention of such accidents, that in July, 1907, experts were appointed especially to deal with this problem. As a result, not only was Bulletin 333, on Coal-Mine Accidents: Their Causes and Prevention, prepared and published, but through personal inspection of foreign testing stations, and a study of their reports and the critiques of their methods and operations, definite plans for the establishment of such a testing station in this country were formulated.

In the latter part of 1907, four grave disasters occurred in close succession consequent on explosions in the Monongah mines in West Virginia, where 368 men were killed, the Darr mine in Pennsylvania, where 160 were killed, the Naomi mine in Pennsylvania, where 34 were killed, and the Yolande mine in Alabama, where 61 were killed. These frightful disasters so quickened the public conscience, and so plainly demonstrated that both humanitarian and economic needs demanded that steps be taken to prevent the recurrence of such accidents, that in 1908 Congress made a special appropriation for an investigation as to the "causes of mine explosions." A similar appropriation was made in the following year. By act of May 16, 1910, the Bureau of Mines was created "to make diligent investigation of the methods of mining, especially in relation to the safety of miners, the use of explosives, the prevention of accidents," and other matters relating to mining. Therefore, these investigations are at present conducted in obedience to an organic act instead of being dependent solely upon special appropriations.

The first appropriation became available July 1, 1908. Through the courtesy of the War Department a portion of the grounds and buildings of the arsenal at Pittsburgh was granted for the use of the technologic branch of the United States Geological Survey. Work was immediately begun in procuring and erecting the necessary instruments and appliances for carrying out the desired tests and investigations and in adapting the existing buildings or in erecting new structures to contain the apparatus. The Pittsburgh testing station was officially opened and regular work was commenced on December 3, 1908, the apparatus and appliances having been tested, the force drilled in their use, and the equipment and methods inspected and passed upon by foreign experts.

A special feature of the station is the appliances for investigating and testing explosives to determine their suitability for use in coal mines. The apparatus employed, the methods of using it, and the results obtained in testing 23 different explosives are set forth in this bulletin. An important part of the plant is a well-equipped chemical laboratory where the explosives are carefully analyzed and studied to ascertain their chemical properties. Here the gas-air

mixtures into which the explosives are fired and the coal dust used in this connection, the igniters or detonators employed, and the products of explosion are analyzed. The extent to which this chemical work is carried on is shown by the report on the tests of four foreign explosives, also given in this bulletin.

At the outset it was recognized that in order to correlate the behavior of explosives, a standard of reference must be selected. Modern practice indicated that this must be a "detonating" rather than a "burning" explosive, and after due consideration and inquiry, a dynamite of the following composition was selected: Nitroglycerin, 40 per cent; sodium nitrate, 44 per cent; wood pulp, 15 per cent; calcium carbonate, 1 per cent. It should be definitely understood that this standard was adopted solely for the purpose of comparing and standardizing the characteristics developed by an explosive when it is fired, and that this standard is not an ideal explosive for use in coal mines. On the contrary, it is quite unsuitable for such a purpose. It was selected because it is well known through long use, is comparatively simple in its composition, and is easy to reproduce. Having standardized by its means the characteristics of an explosive, determination can then be made of the relative fitness of the explosive for use in coal mines by subjecting it to various tests described in this bulletin. These tests are based on the practices and are confirmed by experiences at foreign testing stations.

The last-mentioned terms are intentionally used in the plural for when the investigation of European testing stations referred to above was made in 1907 the methods and practices pursued at these stations were found to vary widely. The subsequent more searching inquiry made on behalf of the technologic branch by Axel Larsen disclosed the fact that not only did the foreign testing galleries differ in form, dimensions, material, and location (on or beneath the surface of the earth) but that the character of the explosive mixtures used within the galleries also differed. Likewise various methods were used in proving the characteristics and composition of these mixtures, and in firing the explosives. Moreover it was found that the requirements as regards other tests than gallery tests were not identical. But it was shown by statistical investigations that in all countries where testing stations were maintained the loss of life in coal mining was diminished, though, because of the many factors which enter into the problem, it was not possible to show the specific effects of the testing of the explosives or of the regulations governing their selection and use.

In determining the character of the tests to be applied at the Pittsburgh station account was taken of these differences, and it was decided that the details of the tests must be worked out to satisfy the conditions imposed by the particular compositions of the gas and

coal dust available for use. This was done, and under date of January 8, 1909, the Director of the Geological Survey issued a notice to manufacturers of explosives in the United States to the effect that official tests of such explosives as the manufacturers might desire to have tested as to their permissibility for use in coal mines, would be made at the Pittsburgh station. This notice described the test requirements to which explosives would be subjected, and set forth the conditions under which the explosives would be received. A copy of the test requirements is appended to this bulletin. Inspection of the requirements shows that a permissible explosive is not only one that has passed the prescribed tests, but is such only when it has the composition and characteristics of the sample submitted for test, and then only when it is used under the prescribed requirements as to quantity used, condition (that is, not frozen), method of confinement, and device for firing it.

The United States Government does not compel nor prevent the use of any explosive or prescribe the conditions of use. It only advises the public as to the character of explosives and as to the manner in which they should be used. It is, therefore, gratifying to state that the manufacturers of explosives in this country cooperated so promptly and so cordially in the endeavor to protect the lives and persons of those engaged in mining coal that by January 1, 1910, there had been received 51 applications for the testing of 134 different explosives. During that year 64 of the explosives submitted were tested and 36 of these passed the tests required to place them on the list of permissible explosives.

The data obtained in testing the dynamite chosen as a standard, the black blasting powder, which up to the founding of the Pittsburgh testing station was used almost universally as the explosive agent in our coal mines, and the first 17 explosives which passed the prescribed tests and were placed on the permissible list, are recorded in this bulletin, so that the results upon which the decision was based in each case may become commonly known and may be freely exposed to criticism by those competent to pass upon these matters. The results of the tests of four foreign explosives which have been tested at the European stations are also given in order that data may be supplied through which to correlate or differentiate the conditions, methods, and requirements of the different governmental stations.

To promote the general interest in this inquiry and to extend among the consumers of explosives such a knowledge of them as will lead to their more intelligent and efficient use, a chapter has been devoted to the consideration of the nature and properties of explosives. Likewise, a chapter on thermochemistry has been added to assist the manufacturer in compounding his materials so as to make an explosive which will satisfy the special requirements of coal mining.

CHAPTER I.

NATURE AND COMPOSITION OF EXPLOSIVES.

By WALTER O. SNELLING.

CHEMICAL NATURE OF EXPLOSIVE MATERIALS.

When combustible matter of any kind is ignited in the presence of air, certain manifestations occur, which are styled "combustion," and it is said that the material "burns." The combustible material unites chemically with the oxygen of the air, and this union gives rise to heat and other phenomena which always accompany active combustion.

Nearly all the explosives in use at present depend for their action on the chemical union of combustible material with oxygen, and it is mainly in the extreme rapidity of the combustion, due to the closeness with which the particles of combustible matter are associated with oxygen in explosive bodies, that the action of explosives differs from the burning of ordinary inflammable substances. Gunpowder, for example, consists of a mixture of potassium nitrate, sulphur, and charcoal. Sulphur and charcoal are combustible, and potassium nitrate contains a large proportion of oxygen which is so held that under suitable conditions it is readily given up. When a grain of gunpowder is heated to its ignition temperature, the potassium nitrate gives up part of its oxygen under the influence of the heat, and the sulphur and charcoal at once burn vigorously in the oxygen thus evolved. This burning of the sulphur and charcoal produces much heat, which raises the temperature of surrounding particles of powder to the ignition temperature, and causes them to burn. As the particles of potassium nitrate are intimately associated with the particles of sulphur and charcoal, each particle of sulphur and charcoal is in contact with a source of oxygen, and therefore the burning of gunpowder is extremely rapid.

Gases are formed by the burning of the charcoal and sulphur, and these gases are highly heated and expanded by the large quantity of heat produced. The gases in their expanded condition have a volume several hundred times as great as the powder from which they were formed, and it is to the sudden formation of these large volumes of highly heated gases that gunpowder and other explosives owe their strength and their power of doing work.

The volume of gas produced and the heat liberated by the combustion of different materials vary greatly. Likewise there are many

materials that do not produce gases when they burn. When powdered aluminum, for example, is mixed with an oxidizing agent and ignited, very great heat is produced, but no gases are formed because the substance produced by the union of aluminum and oxygen is a solid that is not volatile at ordinary temperatures. When charcoal (which consists principally of carbon) is burned, a gas, carbon dioxide, is produced, and this gas tends to occupy a space many hundred times the volume of the carbon from which it was formed. As most explosives owe their power entirely to the expansive action of great volumes of gas set free at the moment of combustion, it can readily be seen why carbon, either in the form of charcoal, or combined with other elements in the form of starch, wood pulp, etc., forms one of the constituents of so many explosives, and why aluminum and similar materials, which yield no gaseous products of combustion, are seldom so used.

Since the rapidity of burning of any material depends in large measure upon the proximity of its combustible components to oxygen, in the manufacture of gunpowder the charcoal, sulphur, and potassium nitrate used are very finely pulverized, well mixed, and pressed together, so that the particles of combustible material will be in close contact with the source of the oxygen required for their combustion. In a few compounds (of which nitroglycerin is a good example) combustible materials and loosely held oxygen exist in the same chemical substance. In such compounds the association of oxygen with combustible materials is much closer than it can be in a mechanical mixture such as gunpowder, and the explosive action of these materials is therefore far more rapid and powerful.

Nitroglycerin is a heavy viscous liquid formed by the action of a mixture of strong nitric and sulphuric acids upon ordinary glycerin. The chemical change that takes place through the action of the mixture of concentrated nitric and sulphuric acids upon glycerin and similar materials is called "nitration." It results in the introduction of weakly held oxygen into the glycerin molecule, this oxygen being directly united to nitrogen, a chemical element for which it has a comparatively weak affinity. Only when the chemical stability of nitroglycerin is disturbed, as by heat or percussion, does the stronger affinity of the oxygen for carbon and hydrogen, which form the combustible constituents of nitroglycerin, cause it to unite with them, and thus to bring about the explosion of the compound. Although it differs chemically from glycerin, nitroglycerin closely resembles un-nitrated or ordinary glycerin in appearance, the color and viscosity of the two substances being closely similar.

When nitroglycerin was first used commercially it was ignited by a fuse in the same way that gunpowder is, under these conditions forming an explosive material not much stronger than gun-

powder. Discovery was soon made, however, that if nitroglycerin is exploded by firing a small charge of fulminate of mercury in contact with it, it develops enormously greater force than when simply ignited by means of a fuse. This discovery marked the real beginning of the knowledge and use of high explosives.

It is well known that when a small piece of lead or copper is placed upon an anvil and struck a violent blow with a hammer, it becomes hot, the energy of the blow being transformed into heat, which raises the temperature of the material struck. It is probable that the main reason the explosion of a small charge of fulminate of mercury causes nitroglycerin to explode so violently is because the energy of the blow caused by the explosion of the fulminate is transformed into heat at the point of contact with the nitroglycerin, suddenly raising its temperature much higher than its ignition point. The nitroglycerin in immediate contact with the charge of fulminate is thus exploded, and the shock produced by the explosion of this portion of the nitroglycerin is in a similar manner transformed into heat. This raises the temperature of the surrounding nitroglycerin to a point well above its ignition temperature, and the explosion is thus almost instantly transmitted through the entire mass of nitroglycerin.

Since a shock or blow is transmitted or carried through a body such as nitroglycerin much more rapidly than flame can be transmitted from particle to particle, the explosion of the material is far more rapid and violent when started by the blow from mercury fulminate than when started by simple ignition of the material. The name "detonation" has been given to this form of explosion to distinguish it from the less rapid and violent form of explosion produced by the combustion of such materials as gunpowder, in which transmission of flame takes place from particle to particle of the material. Although the combustion of gunpowder and other explosives of that type is extremely rapid, the detonation of nitroglycerin and similar explosives is so much more rapid that it may be considered to be instantaneous.

DISTINCTION BETWEEN DETONATING AND SLOW-BURNING EXPLOSIVES.

As already noted, explosives owe their effects to the development, at the moment of explosion, of enormous quantities of gas, which tend to occupy a space hundreds of times greater than that which served to contain the explosive before it was fired.

In the case of explosives which detonate, the transformation of the substance into gas at the moment of explosion is practically instantaneous, and accordingly the pressure produced by the gases thus formed is sharp and sudden. In a period of time less than the thousandth of a second, the explosive is transformed by the chemical

reactions taking place into gases which tend to occupy several hundred times the original volume of the explosive. Everyone who has witnessed the firing of charges of detonating explosives is familiar with the shattering and rending effects produced as the result of this instantaneous development of great quantities of gas.

Many explosives which do not detonate produce fully as much gas as detonating explosives do, but because the explosive reactions take place more slowly, the development of the gas is more gradual and the pressure produced by the explosion, instead of being very high and of short duration, is lower and more prolonged.

For certain purposes the shattering effect produced by detonating explosives is of great value. Such explosives find a wide field of usefulness in blasting and tunneling in hard and tough rock, in breaking up old metal castings, and for similar purposes. In like manner, explosives of slower action have advantages over detonating explosives for many kinds of work. In order that an explosive may be a suitable agent to act as a propellant in guns, it is essential that its action should not be too quick. A certain length of time is required to set the projectile in the gun in motion, and if a detonating explosive were used, its rapidity of action would be so great that, before the ball could be set in motion, the pressure produced by the gases formed would burst the gun.

The term "high explosive" is ordinarily applied to explosives whose usual manner of action is by detonation, and the term "low explosive" is applied to those in which the slower form of reaction ordinarily takes place.

These terms have the advantage of convenience, but the fact should not be lost sight of that they do not rigidly classify explosive compounds, since many materials will either detonate or burn quietly, depending upon the manner in which the initial decomposition is brought about and upon the physical state of the explosive. Nitrocellulose, for example (an explosive produced by nitrating ordinary cotton by means of a mixture of nitric and sulphuric acids, and often spoken of as "guncotton"), finds its largest use as a slow-burning or propellant agent in cannon and small arms, the smokeless powder of the United States and several foreign nations consisting essentially of nitrocellulose. As thus used, nitrocellulose is a low explosive, but if it be fired by means of a charge of fulminate of mercury, it detonates, and under these conditions is a high explosive, its strength and action not differing greatly from that of nitroglycerin.

In order to obtain satisfactory results from low explosives, the charge must be confined, but the action of detonating explosives is so rapid that if simply laid upon rock or other material and exploded they exert a strong rending and shattering effect, although it is to be noted that under these conditions the effect is less than when the

explosive is properly confined. When large quantities of gunpowder and similar low explosives are fired, as in the case of an explosion of a magazine, shattering effects similar to those of high explosives are often produced, but in this case it is the effect of the great quantity of explosive that brings about these results, the total quantity of gases produced by the explosion being so great that the innermost portions of the gunpowder are more or less confined by the enormous volumes of gas produced about them.

USE OF NITROGLYCERIN IN EXPLOSIVE MIXTURES.

For a number of years after its discovery nitroglycerin was little used, as its liquid state made it inconvenient for blasting and similar purposes, and its extreme sensitiveness to shock made it dangerous to handle. Later both of these difficulties were overcome by absorbing nitroglycerin in a suitable porous material, and to this mixture the name "dynamite" was given. Infusorial earth (also known as kieselguhr), a substance which, like chalk, is composed almost entirely of shells of microscopic organisms, was found to be best suited as an absorbent for nitroglycerin. It is abundant in many parts of the world, and forms beds of considerable thickness that represent former sea-bottom deposits.

Infusorial earth is able to take up several times its own weight of nitroglycerin, thus producing a pasty or plastic mass having somewhat the consistency of wet sawdust. A mixture of 1 part by weight of infusorial earth with 3 parts of nitroglycerin is called a 75 per cent dynamite, as it contains 75 per cent by weight of nitroglycerin; and, similarly, a mixture of 2 parts by weight of infusorial earth and 3 parts of nitroglycerin is known as 60 per cent dynamite.

The nitroglycerin is simply held mechanically in the infusorial earth, each of the microscopic shells and shell fragments of which that material is composed being covered by a film of nitroglycerin, held by capillary attraction. Infusorial earth has no explosive properties, and accordingly plays no part in the explosive action of dynamite, the strength of the explosive being simply that of the nitroglycerin present, modified and weakened slightly by the presence of the chemically inert absorbent material.

It is evident that additional strength can be given to dynamite if, instead of an inert material like infusorial earth, an active explosive agent be used as the absorbent for the nitroglycerin. Dynamites containing kieselguhr, chalk, or other inert absorbent materials have at the present time been almost entirely replaced by dynamite with an active base consisting usually of a mixture of sodium or potassium nitrate with wood pulp, sawdust, or charcoal. Such a base is practically a low-grade gunpowder.

When dynamite made with an active absorbent mixture is exploded, the detonation of the nitroglycerin fires the gunpowder mixture,

which serves by the heat of its combustion to still further expand the gases produced by the decomposition of the nitroglycerin. In this way, as well as by the gases that it produces, the gunpowder mixture increases the strength of the explosive.

A still more important advantage of the use of an active base in the preparation of dynamite is the manner in which the force of the explosive is modified as the result of the presence of the active absorbent. The explosion of nitroglycerin alone, as has been seen, is extremely rapid, and only at the instant of detonation are the gases produced by its decomposition highly expanded. The explosive action of gunpowder mixtures is much slower, and in dynamites having an active base the heat produced by the combustion of the wood pulp in the oxygen set free from the nitrate serves to keep in an expanded condition the gases formed by the decomposition of the nitroglycerin. This not only adds to the power of the explosive, but also modifies its action in such a way as to considerably increase its effectiveness in blasting. The explosion of the nitroglycerin serves to shatter the rock, and the action of the gunpowder base in maintaining the gases at a high temperature serves to give duration to the gas pressure, and thus to add a heaving force to the blow which is produced by the nitroglycerin alone.

Dynamite is put up in cylindrical cartridges of heavy paraffined paper. Usually these cartridges are about 8 inches long and 1 or $1\frac{1}{4}$ inches in diameter, but cartridges varying in diameter from three-fourths of an inch to 3 inches, and of different lengths to suit special conditions or the desires of different purchasers, are also made. A cartridge measuring 8 by $1\frac{1}{4}$ inches contains about one-half pound of dynamite.

The composition of two typical dynamites of different strength is given in the following table:

Composition of two typical dynamites.

Constituents.	45 per cent dynamite.	60 per cent dynamite.
Moisture.....	1	1
Nitroglycerin.....	45	60
Sodium nitrate.....	41	20
Calcium carbonate.....	1	1
Wood pulp.....	12	18
	100	100

Other constituents besides those mentioned are sometimes used in dynamite. A part of the nitroglycerin may be replaced by ammonium nitrate or by a nitrated compound. Other combustible materials are also substituted for wood pulp. All the constituents of dynamite tend to take up moisture, and most dynamites contain from 0.5 to 1.5 per cent of moisture, which was present in the original

ingredients or was taken up in the course of manufacture and storage. Calcium carbonate is added to dynamite to neutralize any acidity that might develop in the nitroglycerin, it being found that nitroglycerin sometimes tends to decompose in this way. It is claimed that dynamite containing a substance like calcium carbonate is somewhat safer to store and handle than dynamite not containing such a constituent.

The conditions under which nitroglycerin is present in dynamite serve to protect it in a considerable measure from the influence of shocks and blows, and dynamite is much less sensitive and less liable to accidental explosion than is nitroglycerin alone. It is not dangerous to handle and use if proper care is taken and if it is protected from shocks and blows of great violence and from too high a degree of heat.

PERMISSIBLE EXPLOSIVES.

In explosives for use in the open air, such as, for example, quarrying or railroad excavation, strength and efficiency in removing rock are the qualities that are most important, and usually are the only ones that need consideration in the selection of a suitable explosive. Explosives that are to be used in tunneling must not only possess strength and efficiency but also be of such composition that upon exploding they will not give off large quantities of poisonous or offensive gases. In explosives intended for use in coal mines, a further property is most important. Besides possessing the qualities of strength, efficiency in breaking down coal, and freedom from poisonous explosion products, the explosive should be of such nature as not readily to ignite explosive mixtures of gas or coal dust.

The underlying causes for one explosive being safer than another in the presence of explosive mixtures of gas or coal dust have been investigated during the past few years. The many thousands of lives lost in coal-mine disasters have shown the necessity of such investigations, and have stimulated to a marked extent researches in regard to the preparation of explosives suitable for use in coal mining. It has been found that every known explosive, if fired in a sufficiently large charge, will cause the ignition of an explosive gas mixture, but explosives have been found to differ widely in regard to the amount that can be fired without causing such ignition. Ordinary black blasting powder, for example, will cause the ignition of explosive gas mixtures very readily, as little as 25 grams (somewhat less than an ounce) invariably serving to bring about this result. Certain other explosives, in quantities as great as 1,000 grams (2½ pounds), after repeated trials, under conditions exactly similar to those used in testing black powder, have invariably failed to cause ignition of the explosive gas mixtures.

In certain European countries where regulation of the manufacture and use of explosives is recognized as a proper means of safeguarding life and protecting users of explosives from dangerous compounds that might be made and sold by persons not possessing sufficient knowledge or technical skill, all explosives intended for use in coal mining are subjected to tests to determine their fitness for such use. Only explosives that can be fired in charges equal to those employed in mining work, without causing the ignition of explosive mixtures of fire damp, are allowed to be used in coal mining. The explosives that pass the required tests for safety in the presence of gas, for keeping qualities, for safety in handling, etc., are called "permitted explosives," and their use is allowed in coal mines under such regulations as are found necessary to insure safety in handling and loading and the employment of proper means of firing.

In the United States, in the absence of a national law covering the use of explosives, authority controlling the use of such materials lies with the legislatures of the several States. Up to the present day the regulations in different States have been far from uniform and in many States have been inadequate. Accurate information in regard to the action of different kinds of explosive materials is necessary for efficient legislation, and such information has been nowhere available. It is to remedy this condition and provide accurate data in regard to explosives, that tests of coal-mining explosives are being made by the Bureau of Mines. These tests serve to show which explosives are safe and which are dangerous for use in coal mining, and to determine such other properties of explosives as are of importance in the safe and efficient use of these materials.

All explosives that satisfactorily pass such tests as show that they can be fired in considerable quantities in explosive gas mixtures without causing ignition, and in addition possess such qualities of stability, etc., as make them reasonably safe to handle and transport, are termed "permissible explosives." Only such explosives are deemed suitable for use in coal mines in which dangerous quantities of fire damp or inflammable coal dust are likely to be met.

Permissible explosives of most varied composition have been prepared, but in all of them the explosive power is due to the reaction of oxygen with combustible elements, such as carbon and hydrogen, the composition of the explosives being such that the temperature resulting from this combustion is not so high, nor so long continued, as with ordinary explosives. An inflammable gas mixture can be ignited either by a very high temperature acting for a short interval of time, or by a lower temperature acting through a longer space of time; but if a low temperature only is produced by the explosive, and this temperature is of very short duration, the ignition

of the explosive gas mixtures is much less likely. Accordingly the problem of making explosives for use in coal mines is seen to be, in its simplest form, the making of an explosive, that, although producing a low temperature of short duration, shall nevertheless produce a sufficient quantity of gases, and at sufficient pressure to perform by their expansion the work for which the explosive is intended. Through scientific studies and experimentation, manufacturers of explosives have found ways of obtaining this result. Nitroglycerin, ammonium nitrate, and other well-known explosive materials are combined with various substances so as to form explosives that, when properly used, so greatly diminish the risk of accidental ignition of fire damp or coal dust that it may be said to be practically eliminated.

CHAPTER II.

THERMOCHEMISTRY OF EXPLOSIVES.

By WALTER O. SNELLING.

GENERAL THERMOCHEMICAL CONSIDERATIONS.

With all chemical changes there are involved energy changes, and these usually take the form of absorption or evolution of heat. In a few special cases energy in some form other than heat, as electricity, for example, is produced as the result of chemical reactions, but it may be assumed as a general rule that an energy change, usually with the evolution of heat, will be a part of every chemical reaction. It is important to note that the energy changes connected with any particular chemical reaction are definite in quantity, and are quite as susceptible of measurement and exact determination as the chemical products which result from the alterations of the reacting bodies. The study of the heat evolved or absorbed in connection with chemical changes forms the field of thermochemistry. When physical changes occur without any corresponding chemical change, energy changes may also take place, leading to the absorption or evolution of heat. For example, to change a certain quantity of liquid water at its boiling point (100°C.) to gaseous water at the same temperature a certain quantity of heat is required. Another example of physical change accompanied by heat transfer is when a solid body, at any temperature, is dissolved in water at the same temperature. In such a case, where no chemical change results from the mixing of the solid and the water, heat is usually absorbed.

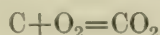
It is necessary to have some unit by which heat changes may be measured, and the unit that has been adopted is called the "calorie." By definition a calorie is that quantity of heat which is required to raise the temperature of 1 gram of water 1°C. As the quantity of heat required to raise the temperature of water 1° varies slightly at different temperatures, it is desirable in accurate work to still further define the calorie, and for the calculations that follow the calorie is defined as "that quantity of heat necessary to raise the temperature of 1 gram of pure water 1°C. , from the temperature of 15° to that of 16°C. "

Some writers have used the unit called the "mean calorie," this being the average quantity of heat required to raise 1 gram of water 1° between the temperature of 0° and 100°C. The unit actually used is one one-hundredth of the quantity of heat required to raise

1 gram of water from 0° to 100° C., this being a value that can be determined experimentally with considerable accuracy. Very careful measurements have shown that the quantity of heat required to raise 1 gram of water from 15° to 16° C. is almost identical with the "mean calorie," and accordingly these values may be considered as interchangeable in all except the most exact work.

A few writers have preferred to use a heat unit larger than that here defined, and have taken as a standard the amount of heat required to raise 1,000 grams of water 1° C. This value is found in a number of books on chemistry, and is termed the kilogram calorie or "large calorie." Considerable confusion has resulted from the use of the same word calorie, to denote two different values, and in consulting tables of thermochemical data it is always necessary to notice carefully whether the "large calorie" or the "gram calorie" is taken as the standard. In the figures given in the present paper "calorie" in every case refers to the gram calorie, as above defined.

Every chemical equation expresses a reaction between definite quantities of matter, and the relation between the quantities of the varying substances entering into the reaction may be determined by calculation. As the methods by which such calculations are made, and the significance of the atomic and molecular weights of the combining materials are treated in all textbooks of chemistry, no detailed description need be given here. A typical reaction, such as



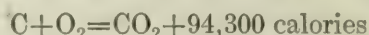
expresses, in addition to the simple information that carbon unites with oxygen to form carbon dioxide, information in regard to the quantities of material that react, and the equation may be read:

One chemical equivalent, or 12 parts by weight, of carbon, unites with two chemical equivalents, or 2×16 parts by weight, of oxygen, to form one chemical equivalent, equal to 44 parts by weight, of carbon dioxide.

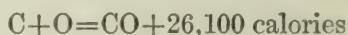
The number of parts by weight that each equivalent represents is found by reference to a table of atomic weights. In the calculations that follow, the atomic weights used will be expressed as whole numbers, the variations that many atomic weights show from whole numbers being neglected for the sake of simplicity. It is evident that in a chemical equation the number of "parts by weight" is entirely independent of the nature of the unit of mass taken, so that in the equation represented above it can be assumed that the "12 parts by weight" of carbon refers to 12 ounces, or 12 pounds, or 12 grams, etc., and in each case the relationship expressed by the equation will hold good if the same unit of mass be used for each of the other substances involved in the reaction. In chemical work it is customary to use the gram as the standard of weight, and thermo-

chemical tables in stating the heat of reaction of a substance usually make use of either the gram or the molecular weight of the substance expressed in grams, as the unit of quantity.

Having accepted standards in which the quantity of material entering into a chemical reaction may be stated, and having taken units by which the heat change produced in the reaction can be expressed, it becomes possible to systematically classify all thermochemical data. In the reaction that has already been referred to, in which 12 grams of carbon unite with 32 grams of oxygen to form 44 grams of carbon dioxide, it has been found that 94,300 gram-calories of heat are evolved. This fact may be conveniently expressed as follows:

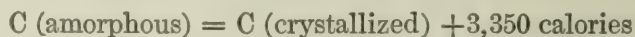


When 12 grams of carbon unite with 16 grams of oxygen to form carbon monoxide, 26,100 calories are evolved, and this fact is expressed in a similar way:



Carbon is an element that exists in several modifications, and accordingly it becomes necessary to state which variety of carbon has been used in any chemical equation, since the heat changes differ with different modifications. Carbon in the form of graphite produces a smaller quantity of heat when burned to form carbon dioxide than does carbon in the amorphous condition, such as charcoal.

Berthelot, to whose work we owe much of our present knowledge of thermochemistry, adopted crystallized carbon (diamond) as the standard form to which all thermochemical data in regard to carbon should be referred. As use is made of many of the values determined by Berthelot in all work with explosives, it is desirable to refer all thermochemical data regarding carbon to the same standard that he used, although for many reasons it would have been better if Berthelot had reduced all his results to amorphous rather than to crystallized carbon. Thermochemical values based upon the use of amorphous carbon may be recalculated in terms of crystallized carbon, since the thermal change involved in the transformation of amorphous to crystallized carbon has been calculated. This value is:

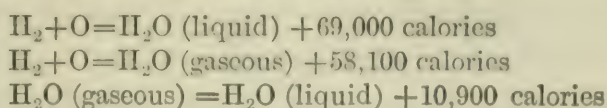


Accordingly, in any reaction 12 grams of amorphous carbon will evolve 3,350 calories more than will 12 grams of crystallized carbon, and this same relation will hold good in regard to any energy changes in which carbon is involved.

In expressing thermochemical changes it has been found desirable to assume that the thermal value of all elements is zero and to estimate all heat transfers upon this assumption. It has already been seen that when carbon unites with oxygen to form carbon dioxide, 94,300 calories are evolved. Since the thermal values of carbon (crystallized)

and of oxygen are taken as zero, the 94,300 calories evolved in this union of carbon and oxygen represents the fundamental quantity of heat in regard to 1 gram-molecule of carbon dioxide produced. Thus, the amount of heat produced when any material is formed from its elements is called its "heat of formation," and represents the energy bound in the compound by virtue of the affinity of its elementary constituents.

The heat of formation of a material varies with the physical condition in which it exists. Thus, the heat of formation of liquid water is 69,000 calories, while that of gaseous water is 58,100 calories, and the difference between these two values represents the thermal change involved in this transformation of liquid water to gaseous water. The three equations may be thus represented:



The quantity of heat produced in any chemical reaction has been found to vary according to the temperature at which the reaction occurs. But, if the substances entering the reaction and the products resulting from the reaction are brought to the same temperature, so that the initial and final states of the system are the same, the equation is unaffected by the temperature at which the reaction takes place. In expressing all thermal values it is customary, except where a note is made to the contrary, to take 0° C. as the initial and final temperature of the reacting substances.

It is one of the laws of thermochemistry that the quantity of heat liberated or absorbed by any set of chemical changes depends solely upon the initial and final states of the system, and is the same whatever the nature of the intermediate steps. Noting, therefore, that all thermochemical equations indicate the amount of heat liberated or absorbed in the reaction of the original substances, at 0° C., with the formation of the resulting products, also brought to 0° C., it will be seen that the thermal value which the equation gives represents solely the energy changes involved in the transformation of the original to the final substances, and is not in any way connected with the reactions by which these changes have been brought about. Because of this fact it is possible to make calculations in regard to the heat produced by explosives, although the changes which occur in many of the reactions are very complicated and are only imperfectly known.

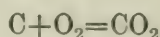
THERMOCHEMISTRY OF CARBON DIOXIDE AND CARBON MONOXIDE.

Carbon, either as the element or combined with other elements to form cellulose, starch, or similar compounds, is the principal combustible constituent used in the preparation of commercial explosives.

In gunpowder, carbon is used in the form of charcoal. Pure charcoal is amorphous carbon and ordinary charcoal consists mainly of amorphous carbon, but also contains a small proportion of hydrocarbon compounds. Nitroglycerin consists of carbon combined with other elements, and in dynamite carbon is present not only as a component of the nitroglycerin but also as an essential constituent of the wood pulp or other active absorbent agent used.

It will accordingly be seen that the oxidation of carbon forms one of the principal reactions that occur in the chemical transformations involved in the decomposition of all commercial explosives. For that reason information in regard to the heat produced when carbon combines with oxygen in different proportions becomes of particular interest.

In regard to the reaction



it has already been noted that the heat evolved amounts to 94,300 calories when the weights, expressed in grams, of the reacting substances taken correspond to their chemical equivalents. Under standard conditions of temperature and pressure the volume occupied by the molecular weight of a gas, expressed in grams, has been found to be constant for all gases, and to be equal to 22.4 liters. Since both the oxygen taken and the carbon dioxide produced in the reaction given are in gram-molecular quantities, the oxygen represented in the equation will have a volume of 22.4 liters, and the carbon dioxide produced will have the same volume, when both are measured under standard conditions of temperature and pressure. It will, therefore, be seen that no change in volume occurs in this reaction when the components and the products of the reaction are taken in their actual state under ordinary conditions of temperature and pressure.

The specific heat of a substance is the ratio of the quantity of heat required to raise the temperature of a gram of the substance $1^\circ\text{C}.$, to the quantity required to raise the temperature of a gram of water $1^\circ\text{C}.$ The molecular heat of a substance is its specific heat multiplied by its molecular weight. The heat capacity of a mixture may be defined as the sum of the products obtained by multiplying the specific heat of each constituent by its weight in grams, or as the sum of the products obtained by multiplying the molecular heat of each constituent by the number of gram-molecules of that constituent present.

The specific and molecular heats of gases have been found to increase with temperature, and, in general, it may be said that

$$(1) \quad c = a + bt$$

where a is the molecular heat of the gas at $0^\circ\text{C}.$, b the increment of the mean molecular heat of the gas for $1^\circ\text{C}.$, c the mean molecular heat of the gas at constant volume from $0^\circ\text{C}.$ to $t^\circ\text{C}.$, and t the temperature to which the gas is raised.

The mean molecular heat of carbon dioxide between 0° and $3,000^{\circ}$ C. has been measured, and is stated by Mallard and Le Chatelier^a to be

$$c = 6.26 + 0.0037t$$

By the aid of this equation the temperature to which a given quantity of heat will raise a definite quantity of carbon dioxide can be calculated; and since the temperature to which a substance is raised by a given quantity of heat is expressed by the equation:

$$(2) \quad t = \frac{Q}{c}$$

where Q is the number of calories available to raise the temperature of the material, c is the mean molecular heat of the material within the range over which its temperature is to be changed, and t is the resulting temperature, there is obtained by combining (1) and (2) and transposing the formula:

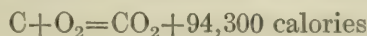
$$(3) \quad t = \frac{-a + \sqrt{a^2 + 4b \times Q}}{2b}$$

which indicates the temperature to which the gram-molecular quantity of any gas at constant volume can be raised by a given quantity of heat, Q . It should be noted that these equations involving a , b , c , t , and Q are general ones and are true not only when c represents molecular heat, but also when it represents heat capacity, provided that in each case the value Q applies to the same quantity of material as the factor c .

In the reaction of carbon with oxygen to form carbon dioxide $Q = 94,300$, and in the formula for the molecular heat of carbon dioxide $a = 6.26$ and $b = 0.0037$. Substituting these values for a , b , and Q there is obtained:

$$\begin{aligned} t &= \frac{-6.26 + \sqrt{(6.26)^2 + 4 \times 0.0037 \times 94,300}}{0.0074} \\ t &= \frac{31.62}{0.0074} \\ t &= 4,273^{\circ} \end{aligned}$$

The values that are of interest in regard to the reaction of carbon with oxygen to form carbon dioxide may be summarized as follows:



$$\frac{94,300 \text{ calories}}{44} = \text{calories per gram of reacting materials} = 2,143 \text{ calories.}$$

$$\frac{94,300 \text{ calories}}{22.4} = \text{calories per liter of resulting gas} = 4,209 \text{ calories.}$$

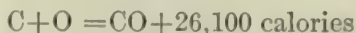
$$\frac{22.4}{44} = \text{liters of gas per gram} = 0.509 \text{ liters.}$$

$$\text{Maximum temperature of reaction at constant volume} = 4,273^{\circ}.$$

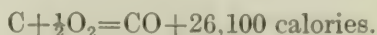
^a Annales des Mines, vol. 163, 1883, p. 524; Comptes Rendus, vol. 93, 1881, p. 1014.

REACTION OF CARBON WITH OXYGEN TO FORM CARBON MONOXIDE.

When carbon unites with oxygen to form carbon monoxide the reaction may be written:



or



The latter form is the better as it expresses in a clearer manner the relationship of the volumes of the gases concerned in the reaction, but the first equation stated is the one more generally found in tables of thermochemical data. In both equations, of course, the same reaction is indicated.

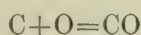
It will be noted that from one-half a gram-molecular volume of oxygen there results, in the reaction of carbon with oxygen to form carbon monoxide, 1 gram-molecular volume, or 22.4 liters, of carbon monoxide; and, as the volume occupied by solid carbon is so small as to be negligible, it will be seen that in the reaction there occurs an increase in volume such that the final gaseous product, carbon monoxide, has twice the volume of the oxygen originally present. Whenever a change in volume occurs in a chemical reaction taking place under ordinary conditions, the gases that are produced do work in overcoming the pressure of the atmosphere, and compensation must be made for the amount of energy that is expended in producing the increase in volume. In the tables of thermochemical data that are given on page 62, the components and products in every reaction are considered in their actual condition at 15° C., and accordingly the energy represented in any change in volume that has taken place in the reaction has already been allowed for.

When gases are formed within a closed space, so that they do not have to overcome the pressure of the atmosphere, their temperature will be higher by an amount that is determined by the energy that would otherwise be expended in overcoming atmospheric pressure. Consequently, as the decomposition of explosives under the condition of their actual employment involves their use in a closed space, such as a bore hole in some solid material, it is desirable to calculate the maximum temperature produced by explosives when the decomposition takes place under conditions of constant volume. As the data used give the results of reactions calculated to conditions of constant pressure, it is necessary to allow for the increased temperature due to the energy available as heat which under conditions of constant pressure would be employed in overcoming atmospheric pressure. As already noted, 1 gram-molecule of any gas occupies, under standard conditions of temperature and pressure, the volume of 22.4 liters. The standard condition of atmospheric pressure is represented by the pressure resulting from the weight of a column of mercury 76 centimeters high. Hence the pressure of 1 atmos-

phere on an area of 1 square centimeter is represented by the weight of a column of mercury 1 square centimeter in cross section and 76 centimeters in height. Since the specific gravity of mercury is 13.596, the pressure of such a column will be 76×13.596 , or 1,033.3 grams per square centimeter.

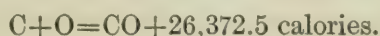
The work done when 1 gram-molecule of gas (22,400 cubic centimeters) is formed against the pressure of 1,033.3 grams per square centimeter, is equivalent to overcoming a pressure equal to the weight of 1,033.3 grams through a vertical distance of 22,400 centimeters. This gives the energy required to overcome atmospheric pressure in the formation of 1 gram-molecule of any gas as equal to 23,145,920 gram-centimeter units, a gram-centimeter being taken as the energy required to lift the weight of 1 gram to a height of 1 centimeter against the earth's attraction. The earth's attraction at 45° latitude is taken as 980.6 dynes, and by the aid of this factor the work done in overcoming atmospheric pressure can be expressed in absolute units. However, since the mechanical equivalent of heat, or the equivalent of 1 calorie in terms of mechanical energy, has been directly determined as 42,719 gram-centimeter units, it is convenient to use this figure. Dividing 23,145,920 by 42,719 gives a quotient expressing the number of heat units represented in the formation of 1 gram-molecule of gas against atmospheric pressure. With the constants assumed in the calculation just made, the result is 542 calories, but the value used in this paper is 545 calories, because some of the constants used in the calculation have slightly different values from those stated.

In order that the equation



shall show the quantity of heat evolved when the reaction takes place under conditions of constant volume, it is necessary to add to the 26,100 calories representing the heat produced at constant pressure, the further sum of 272.5 calories, because of the increase of one-half gram-molecular volume that takes place.

Therefore, in the reaction at constant volume,



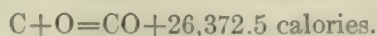
Hence, $Q = 26,372.5$ calories.

The maximum temperature produced in the reaction is determined as follows:

In the equation $c = a + bt$ for carbon monoxide, $a = 4.80$ and $b = 0.0006$. Substituting these values and that of Q in equation (3) on page 21, gives:

$$\begin{aligned} t &= \frac{-4.80 + \sqrt{(4.80)^2 + 4 \times 0.0006 \times 26,372.5}}{0.0012} \\ &= \frac{4.492}{0.0012} \\ &= 3,743^\circ \end{aligned}$$

The most important values relative to the reaction of carbon with oxygen to form carbon monoxide, at constant volume, are as follows:



$$\frac{26,372.5}{28} = \text{calories per gram of reacting materials} = 942 \text{ calories.}$$

$$\frac{26,372.5}{22.4} = \text{calories per liter of resulting gas} = 1,177 \text{ calories.}$$

$$\frac{22.4}{28} = \text{liters of gas per gram} = 0.800 \text{ liters.}$$

Maximum temperature of reaction at constant volume = 3,743°.

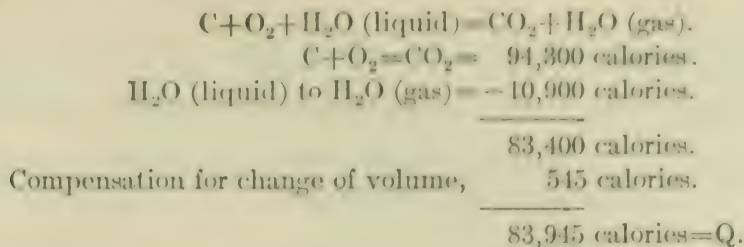
A comparison of these values with those for carbon dioxide brings out the interesting point that although the heat evolved in the reaction forming carbon dioxide is 94,300 calories, as against only 26,372.5 calories in the formation of carbon monoxide, yet the temperatures produced in the two cases are not far different, the maximum temperature in the reaction forming carbon dioxide being 4,273°, and that produced in the formation of carbon monoxide being 3,743°.

When the two calculations are compared it is noted that this result is brought about because of the specific heat of carbon monoxide being so much less than that of carbon dioxide, so that the smaller quantity of heat produced in the last reaction is sufficient to raise the gases formed to a temperature almost as high as when carbon dioxide is produced. This would indicate that it is not possible to materially lower the temperature of any reaction, in which carbon unites with oxygen, by varying the amount of carbon dioxide and carbon monoxide produced, so long as these gases alone are formed in the reaction. If, however, some other material is present in the reaction, or some other gas is formed which can share the heat with the main products of the reaction, it is quite evident that a decided lowering of the temperature would result.

The means that have been taken to lower the flame temperature of explosives without greatly decreasing their energy value will be discussed in another part of this paper, but at this point it seems desirable to show how markedly different the temperatures produced will be in the case of carbon dioxide and carbon monoxide when some other substance enters the reaction to share with the gaseous products the heat evolved by the oxidation of the carbon. As water, either free, in the form of moisture, or combined as water of crystallization, is a material frequently used in explosives to lower the flame temperature, the maximum temperature produced from 12 grams of carbon, burning to carbon dioxide and carbon monoxide, respectively, will now be calculated when 1 gram-molecule of free water is assumed to be present in the reaction.

REACTION OF CARBON WITH OXYGEN TO FORM CARBON DIOXIDE IN THE PRESENCE OF WATER.

The reaction under consideration is represented by the following equations:



In the equation

$$c = a + bt$$

for CO_2 , $a = 6.26$; $b = 0.0037$; for H_2O , $a = 5.61$; $b = 0.0033$ and the mean molecular heats to be used in the calculation are:

$$\text{For } \text{CO}_2, c = 6.26 + 0.0037t.$$

$$\text{For } \text{H}_2\text{O}, c = 5.61 + .0033t.$$

$$\text{Sum of mean molecular heats or heat capacity } c = 11.87 + .0070t.$$

Substituting these last values and that of Q in equation (3) on page 21, gives

$$\begin{aligned}
 t &= \frac{-11.87 + \sqrt{(11.87)^2 + 4 \times 0.0070 \times 83,945}}{0.014} \\
 t &= \frac{38.04}{0.014} \\
 t &= 2,717^\circ
 \end{aligned}$$

In regard to this reaction the principal factors may be thus summarized:

$$\frac{83,945}{62} = \text{calories per gram of reacting materials} = 1,354 \text{ calories.}$$

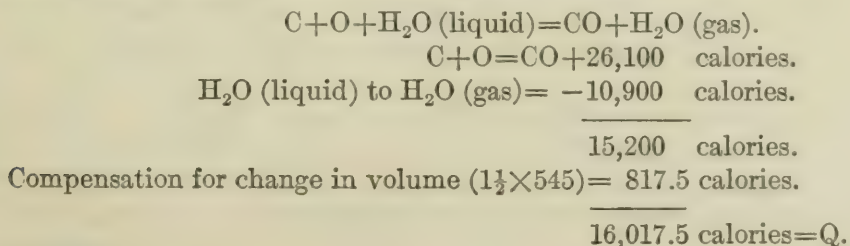
$$\frac{83,945}{2 \times 22.4} = \text{calories per liter of resulting gas} = 1,874 \text{ calories.}$$

$$\frac{44.3}{62} = \text{liters of gas per gram} = 0.722 \text{ liters.}$$

$$\text{Maximum temperature of reaction at constant volume} = 2,717^\circ.$$

REACTION OF CARBON WITH OXYGEN TO FORM CARBON MONOXIDE IN THE PRESENCE OF WATER.

The reaction of carbon with oxygen to form carbon monoxide when water is present may be expressed as follows:



In the equation

$$c = a + bt$$

for CO, $a = 4.80$, $b = 0.0006$; for H_2O , $a = 5.61$, $b = 0.0033$ and the mean molecular heats to be used in the calculation are:

$$\text{For CO, } c = 4.80 + 0.0006t.$$

$$\text{For } H_2O, c = 5.61 + .0033t.$$

$$\text{Sum of mean molecular heats or heat capacity, } c = 10.41 + .0039t.$$

Substituting these values as in the previous cases gives:

$$t = \frac{-10.41 + \sqrt{(10.41)^2 + 4 \times 0.0039 \times 16,017.5}}{2 \times 0.0039}$$

$$t = \frac{8.52}{0.0078}$$

$$t = 1,092^\circ$$

In regard to this reaction, the principal factors may be thus summarized:

$$\frac{16,017.5}{46} = \text{calories per gram of reacting materials} = 348 \text{ calories.}$$

$$\frac{16,017.5}{2 \times 22.4} = \text{calories per liter of resulting gas} = 357 \text{ calories.}$$

$$\frac{44.8}{46} = \text{liters of gas per gram} = 0.974 \text{ liter.}$$

$$\text{Maximum temperature of reaction, constant volume,} = 1,092^\circ$$

The very great reduction of flame temperature which results when carbon monoxide shares its heat with any substance of high specific heat is evident. One of the most important means used to produce explosives of low flame temperature is so to adjust the components of the explosives as to provide an excess of carbon over the quantity required to produce carbon dioxide. By such adjustment of the composition of the explosive, the formation of more or less carbon monoxide is brought about, and a gas of high specific heat, either water vapor or other gas, is provided to take up a portion of the heat produced in the reaction.

The following table presents the more important factors relative to the union of carbon and oxygen to form carbon monoxide and carbon dioxide in the four reactions just studied:

I....	$C + O_2 = CO_2 + 94,300 \text{ calories.}$			
II....	$C + O = CO + 26,100 \text{ calories.}$			
III....	$C + O_2 + H_2O \text{ (liquid)} = CO_2 + H_2O \text{ (gas)} + 83,945 \text{ calories.}$			
IV....	$C + O + H_2O \text{ (liquid)} = CO + H_2O \text{ (gas)} + 16,017.5 \text{ calories.}$			
	I	II	III	IV
Calories per gram of reacting materials.....	2, 143	942	1, 354	348
Calories per liter of resulting gas.....	4, 209	1, 177	1, 874	357
Liters per gram.....	0. 509	0. 800	0. 722	0. 974
Maximum temperature of reaction, at constant volume.....	4, 273°	3, 743°	2, 717°	1, 092°

The quantity of water in the last two equations is greater in proportion to the amount of combustible material than would ever occur in an actual explosive. Accordingly, the equation is of theoretical interest only, but the very remarkable reduction in temperature from over $4,000^{\circ}$, in reaction I, to only about $1,000^{\circ}$, in reaction IV, shows clearly the lowering of the flame temperature that results when carbon monoxide shares its heat with water vapor.

**MAXIMUM TEMPERATURE PRODUCED BY EXPLOSIVES HAVING
NO SOLID PRODUCTS OF COMBUSTION.**

What is called the "explosion" of any chemical compound or chemical aggregate is simply the result of a series of very rapid chemical and physical changes with their associated evolution of heat. In general, certain combustible elements in the explosive are oxidized, and the resulting gases are heated to a high temperature and greatly expanded by the heat evolved from the chemical reactions taking place. The point to be emphasized is, that the chemical reactions that take place during that rapid form of decomposition called "explosion" are not different in their fundamental nature from any of the ordinary chemical reactions.

The quantity of heat produced in any chemical reaction is an absolutely definite quantity, and as the effect of any given quantity of heat in expanding different amounts of gas is also well known, it is evident that information of decided value in regard to the flame temperature of any explosive may be obtained by suitable calculation. Attention has already been called to the fact that the quantity of heat evolved in any chemical reaction, or any set of chemical reactions, depends solely upon the initial and final states of the system, and is independent of the intermediate reactions.

As it is possible to analyze an explosive with considerable exactness, and to determine the constituents of the explosive and the percentage of each present, it is clear that the initial state of the explosive can be readily determined. By firing a suitable charge of the explosive in a cylinder strong enough to withstand the pressure produced, the products resulting from the explosive decomposition of the original material may be obtained, and by analysis of these the final state of the explosive system may be determined. The initial and final states of the explosive system being known, the quantity of heat evolved when the decomposition of the explosive is brought about may be accurately determined since all the factors are known.

The second part of the problem, the determination of the temperature to which a quantity of heat will raise the products of combustion, is at present not capable of very accurate solution, since the laws governing the specific heats of substances at high temperatures are but imperfectly known, and even the laws in regard to the change

in specific heats with increasing temperatures for many common substances are known only approximately.

By using the best values for specific heats that have been determined, information can be obtained in regard to the maximum temperature produced by many explosives. As some of the values entering into such calculations are not known with exactness, and as some are recognized to be mere approximations to true values, it should not be expected that calculations made in this way would have great accuracy. As new and better values are obtained for specific heats of substances at high temperatures, more accurate calculations will become possible, but even with the present data it is possible to obtain values that are of great importance in showing in what direction the change in composition of explosive materials should proceed, in order to obtain explosives of low flame temperature.

As it is to be expected that such errors as enter into calculations of this sort will appear in all calculations equally, it is also apparent that the question whether one explosive will produce a higher flame temperature than another can be answered by calculation. And as the temperatures of explosives that have and of those that have not passed official tests in the presence of explosive mixtures of fire damp or coal dust with air have been calculated, the manufacturer may select, by the aid of such calculations made upon his explosives, those explosives that may most reasonably be expected to show favorable results upon being tested. He will thus greatly lessen the amount of work necessary in testing explosives and also increase his own chances of submitting explosives that shall show favorably in the official tests.

From such calculations as have already been made it would seem that any detonating explosive whose flame temperature, calculated by the method that will be followed in this paper, is lower than $1,700^{\circ}\text{C}$., will be reasonably sure to pass all of the tests required at the Pittsburgh station for inclusion in the "permissible" list. Detonating explosives having flame temperatures (calculated in the same manner) between $1,700^{\circ}$ and $2,200^{\circ}\text{C}$. may or may not pass the tests. Those having temperatures near $1,700^{\circ}\text{C}$. may pass the tests; those whose temperatures exceed $2,000^{\circ}\text{C}$. are much less likely to do so. Explosives whose calculated flame temperatures lie above $2,200^{\circ}\text{C}$. may be assumed to be unworthy of test, since it is extremely doubtful if any explosive having so high a flame temperature could succeed in passing the tests, and even should it do so its charge limit would be so low as to make it unsuitable for general mining purposes.

In all cases where reactions are considered in which the products of explosive decomposition remain for some time under pressure while cooling (as is the case in experiments made in closed bombs, etc.),

there are a number of factors which must be given consideration to enable correct results concerning the maximum temperature produced to be determined. Recent investigations along this line have been made ^a showing the influence of secondary reactions as affecting the explosion temperature as calculated by thermochemical methods. Those who desire an exhaustive treatment of this subject may consult the references cited, but these factors will not be taken up here, since this paper is concerned mainly with the relative explosion temperatures of different explosives, and it is probable that such secondary effects as the reversible reaction between carbon dioxide and hydrogen, for example, or the formation of methane through the reaction of carbon monoxide and hydrogen, would not be sufficiently important to alter the relative positions of different explosives, when tested under identical conditions and calculated by the methods which will be outlined.

In a bulletin now being prepared for publication by the Bureau of Mines the author will take up in detail the influence of the formation of methane and other secondary compounds upon the flame temperatures and pressures involved in the use of permissible explosives, as well as of explosives used in blasting and quarrying. Until the data required for this paper can be assembled the flame temperatures as worked out by the methods herein outlined may be used as tentative results; it is believed that they will answer for most practical purposes.

THE MAXIMUM TEMPERATURE OF EXPLOSION OF NITRO-GLYCERIN.

The chemical changes that take place upon the explosion of nitroglycerin may be represented by the reaction:



Analyses of the liquid and solid products resulting from the explosion of small quantities of nitroglycerin in strong steel cylinders have given results that practically accord with the above equation. The equation represents 4 molecular equivalents of nitroglycerin forming upon explosion 10 gram-molecules of water, 6 gram-molecules of nitrogen, 12 gram-molecules of carbon dioxide, and 1 gram-molecule of oxygen.

From such data it is possible to calculate the number of heat units evolved in the explosion of a given weight of nitroglycerin, the maximum pressure that would be produced if the gases were retained in the space originally occupied by the explosive, and the maximum temperature produced under the same conditions. The reacting

^a Poppenberg and Stephan, *Zeitschr. ges. Schiess-Sprengstoffw.*, vol. 5, pp. 281 and 305; pp. 266 and 310; and pp. 452 and 474.

Kast, Z., *Zeitschr. ges. Schiess-Sprengstoffw.*, vol. 5, pp. 205 and 248; and p. 376.

4 gram-molecules of nitroglycerin are decomposed, and therefore the number of calories represented by the formation of this nitroglycerin, if subtracted from the number of calories represented by the heats of formation of all the final products, will give the number of heat units evolved when the above quantity of nitroglycerin is resolved into its decomposition products.

To calculate the maximum temperature reached it is necessary to consider the water produced in the reaction as existing in the gaseous state, and hence its heat formation is taken as 58,100 calories, instead of 69,000 calories, which would be the value if the determination had been carried out in a calorimeter and the resulting products brought to a temperature below the boiling point of water. The molecular weight of nitroglycerin is 227. As has been noted, it is convenient to use in thermochemical calculations the molecular weight of a substance expressed in grams. In the case of nitroglycerin, therefore, the quantity of material to be considered in the reaction is 227 grams. Owing to the fact that the volume of all gases can be expressed as a very simple relationship to their molecular weights it is convenient to consider in a reaction such a number of molecules as will cause all the figures for gases to come out in molecular quantities. The quantity of oxygen that is produced by the decomposition of 1 molecule of nitroglycerin is one-quarter molecule, and in this calculation, to avoid fractions, 4 gram-molecules of nitroglycerin are assumed to be taken.

To calculate the maximum temperature produced by the explosion of nitroglycerin, according to the reaction

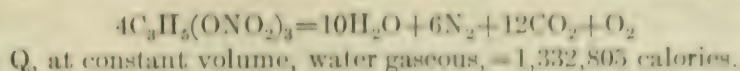


the products of explosion are assumed to occupy the same volume as the original explosive. The calculation is as follows:

Heat of formation of 10 gram-molecules of gaseous water.....	=10×58,100 calories=	581,000 calories.
Heat of formation of 12 gram-molecules of carbon dioxide.....	=12×94,300 calories=	1,131,600 calories.
Compensation for 29 gram-molecules of gas, at constant volume.....	=29×545	= 15,805 calories.
		1,728,405 calories.

The heat of formation of 1 gram-molecule of nitroglycerin is 98,900 calories (see table on p. 62) and the heat of formation of 4 gram-molecules will be $4 \times 98,900 = 395,600$ calories. This amount must be subtracted from the sum of the heats of formation of the products that result from the explosion of the nitroglycerin, thus giving $1,728,405 - 395,600 = 1,332,805$, which is the number of calories evolved when 4 gram-molecules (908 grams) of nitroglycerin is decomposed in the manner expressed by the reaction given. It is con-

venient to represent the number of calories that are evolved in the course of a given reaction by the symbol Q , so that it may be said that



MAXIMUM TEMPERATURE PRODUCED.

The mean molecular heat or the mean specific heat of 1 gram-molecule of H_2O in the form of a gas, at constant volume, is $5.61 + 0.0033t$,^a and of carbon dioxide $6.26 + 0.0037t$.^a Nitrogen and oxygen have the same molecular heat, which is $4.80 + 0.0006t$.^a Since the heat capacity of a mixture of gases, as previously defined, is the sum of the products obtained by multiplying the molecular heat of each constituent by the number of molecules of that constituent, the total heat capacity of the products of combustion is obtained as follows:

The products of combustion are $10H_2O + 6N_2 + 12CO_2 + O_2$. The mean molecular heat of each gas is represented by the equation $c = a + bt$.

Heat capacity of $10H_2O = 10 \times 5.61 + 10 \times 0.0033t = 56.10 + 0.0330t$

Heat capacity of $12CO = 12 \times 6.26 + 12 \times .0037t = 75.12 + .0444t$

Heat capacity of $6N + O = 7 \times 4.80 + 7 \times .0006t = 33.60 + .0042t$

Total heat capacity $c \dots \dots \dots = 164.82 + .0816t$

Substituting in the general equation these values for a and b and the value of Q determined above, the value of t is found:

$$t = \frac{-164.82 + \sqrt{(164.82)^2 + 4 \times 0.0816 \times 1,332,805}}{2 \times 0.0816}$$

$$t = 515.02$$

$$0.1632$$

$$t = 3,155^\circ$$

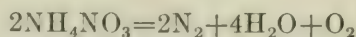
THE MAXIMUM TEMPERATURE OF EXPLOSION OF AMMONIUM NITRATE.

Berthelot^b has found that ammonium nitrate may be decomposed in several different ways, according to the conditions under which its decomposition is brought about. As each of these types of decomposition involves a different chemical reaction and results in products having varying heats of formation, it is evident that the quantity of energy set free by the decomposing of a given amount of ammonium nitrate will depend upon which type of reaction occurs. It is difficult to cause pure ammonium nitrate to explode, but several explosives are in common use that contain large percentages of ammonium nitrate, and the reaction that the ammonium nitrate follows upon the explosion of these materials can be expressed. When associated with other explosive materials—as, for example, with small amounts of nitroglycerin—the detonation of ammonium nitrate is readily brought about. If the associated nitroglycerin is

^a Table 4, p. 61.

^b Sur la force des matières explosives, vol. 1, p. 21.

disregarded and only the reaction that the ammonium nitrate undergoes is considered, the detonation may be expressed by the following equation:



Calculation of Q:

$$\begin{array}{ll} \text{Heat of formation of } 4\text{H}_2\text{O} & = 4 \times 58,100 = 232,400 \text{ calories} \\ \text{Compensation for 7 gas vols.} & = 7 \times 545 = 3,815 \text{ calories} \end{array}$$

$$236,215 \text{ calories}$$

$$\text{Heat of formation of } 2\text{NH}_4\text{NO}_3 \quad = 2 \times 88,050 = 176,100 \text{ calories}$$

$$Q = 60,115 \text{ calories}$$

$$\text{Heat capacity of } 4\text{H}_2\text{O} \quad = 4 \times 5.61 = 22.44 + 4 \times 0.0033t = 0.0132t$$

$$\text{Heat capacity of } 2\text{N}_2 + \text{O}_2 = 3 \times 4.80 = 14.40 + 3 \times .0006t = \frac{.0018t}{.0150t}$$

$$\text{Total heat capacity } c = 36.84 + 0.0150t$$

Substituting these values for a , b , and Q in the general equation gives as the value of t :

$$t = \frac{-36.84 + \sqrt{(36.84)^2 + 4 \times 0.015 \times 60,115}}{2 \times 0.015}$$

$$t = \frac{33.62}{0.03}$$

$$t = 1,121^\circ$$

The method of calculating the maximum temperature produced by an explosive, may be outlined as follows:

From the chemical analysis of the explosive the composition of the explosive expressed in terms of the molecular weights of its constituents is obtained by dividing the percentage of each constituent present by its molecular weight. These figures are then reduced to a more convenient form for calculation by dividing each one by the value obtained for the one lowest in amount. In this manner the number of gram-molecules of each constituent present is represented, when it is assumed that the amount of that constituent present in the smallest quantity amounts to 1 gram-molecule, and the set of figures obtained represents the initial composition of the explosive expressed in gram-molecules. By multiplying the number of gram-molecules of each substance by its molecular weight the total number of grams of material expressed in the equation is indicated. The initial condition of the explosive having been thus represented, the final condition is expressed in gram-molecular quantities by a similar series of calculations based upon the results of the analysis of the products of combustion. The gram-molecular quantities of the products of combustion are readily obtained from the percentage composition found by analysis and the total number of grams of material represented in the equation, as indicated above.

Should the cartridge of explosive analyzed represent absolutely the composition of the material fired in the gage, and should the

analysis of the products of combustion be absolutely exact, the two sides of the equation thus obtained should balance perfectly. But different cartridges of the same explosives vary somewhat; methods of analysis are not absolutely accurate; the collection of gaseous and liquid products of combustion is not easy, and the analysis of these products often suffers from many difficulties and inaccuracies. Hence it is evident that the balancing of the two sides of the equation is never exact, but with careful work the balancing will be sufficiently close to indicate with a very good degree of approximation the course of the explosive decomposition. Allowance is nearly always made in the weighed products of decomposition for the quantity of water which escapes as vapor when the cylinder in which the decomposition takes place is opened.

It will thus be seen that the first step in the calculation is to express the composition of the explosive and of the products of decomposition by chemical formulas, thus obtaining an equation representing the quantity of each material that enters into the reaction and the quantity of each product that results therefrom. From the complete equation representing the reaction the heats of formation of the constituents entering the explosion are determined. In this way the amount of energy that exists in the original material in a bound condition is found. By subtracting this amount from the total heat of formation of all the products resulting from the explosive decomposition there is obtained a measure (Q) of the amount of energy set free in the reaction indicated.

A given quantity, Q , being taken to represent the number of calories produced by the explosive reaction, it is only necessary to obtain the value that shall represent or shall closely approximate the heat capacity of the material in order to determine the temperature that will be reached. Taking all the products of combustion and adding together their heat capacities, a value is obtained representing the total heat capacity of the material of which the temperature is assumed to be raised by the amount of heat produced in the reaction.

The total heat capacity of the products of explosion being determined, the equation

$$t = \frac{Q}{c}$$

(in which c is the total heat capacity and Q is the number of calories produced by the explosion) enables the temperature to be determined.

The most convenient form in which to carry out this calculation has already been mentioned and is represented by the equation

$$t = \frac{-a + \sqrt{a^2 + 4b \times Q}}{2b}$$

where a and b are the two terms of the total heat capacity of the products of reaction, Q is the number of calories evolved in the reaction, and t is the maximum temperature produced.

The method of calculation with an explosive that has no solid products of combustion is shown in the following examples:

Calculation of the maximum temperature of an ammonium-nitrate explosive.

1	2	3	4	5	6
Components.	Formula.	Composition.	Molecular weight.	Column 3 column 4	Column 5 0.01284
Moisture.....	H ₂ O.....	0.60	18	0.03330	2.596
Nitroglycerin.....	C ₃ H ₅ (ON ₂) ₃	8.37	227	.03687	2.871
Ammonium nitrate.....	NH ₄ NO ₃	83.14	80	1.03900	80.92
Wood pulp.....	C ₁₅ H ₂₂ O ₁₀	4.65	362	.01284	1.00
Mono-nitrotoluol.....	C ₇ H ₇ NO ₂	3.24	137	.02365	1.84
		100.00	.....	.....	.....

The following expression represents the composition of the explosive expressed in gram-molecules:



SUM OF MOLECULAR WEIGHTS $\times$ NUMBER OF MOLECULES.

$$\begin{aligned} 2.596 \times 18 &= 46.73 \\ 2.871 \times 227 &= 651.70 \\ 80.920 \times 80 &= 6,474.00 \\ 1.000 \times 362 &= 362.00 \\ 1.840 \times 137 &= 252.10 \end{aligned}$$

Weight in grams of explosive considered in
the calculation..... 7,786.53

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EXPLOSIVE.

$$\begin{aligned} &\text{Grams.} \\ \text{Gaseous} &= 111.8 \\ \text{Liquid} &= 85.7 \\ &\hline &197.5 \\ &2.5 \text{ (loss)} \\ &\hline &200.0 \end{aligned}$$

Assuming this loss to be H₂O,

$$\begin{array}{rcl} & \text{Grams.} & \text{Per cent.} \\ \text{Total H}_2\text{O} & = 88.2 & \text{H}_2\text{O} = 44.1 \\ \text{Total gas} & = 111.8 & \text{or Gas} = 55.9 \\ & \hline & 200.0 & 100.0 \end{array}$$

$7,786.53 \times 44.1$ per cent = 3,433.86, weight in grams of H₂O corresponding to 7,786.53 grams of explosive.

$7,786.53 \times 55.9$ per cent = 4,352.67, weight in grams of gases corresponding to 7,786.53 grams of explosive.

Analysis of gases.

	Percent by volume	Weight in 1 liter.	Percent by weight.	Weight of 1 liter.
		<i>Grams.</i>		<i>Grams.</i>
CO ₂	30.8	0.6052	41.01	1.965
O ₂	1.5	.0214	1.45	1.429
N ₂	67.7	.8489	57.54	1.254
	100.0	1.4755	100.00	

Number of gram-molecules of each of the gaseous products from 7,786.53 grams of explosive:

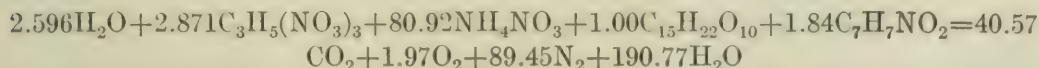
$$\frac{4,352.67 \times 0.4101}{44} = 40.57 \text{ molecules CO}_2$$

$$\frac{4,352.67 \times 0.0145}{32} = 1.97 \text{ molecules O}_2$$

$$\frac{4,352.67 \times 0.5754}{28} = 89.45 \text{ molecules N}_2$$

$$\frac{3,433.86}{18} = 190.77 \text{ molecules H}_2\text{O}$$

It being assumed, then, that the calculation deals with 7,786.53 grams of explosive, the following equation expresses, in gram-molecules, the quantities involved in the explosion:



The following comparison of the quantities of each element found on each side shows that the equation nearly balances:

INITIAL STATE.		FINAL STATE.
378.107	Hydrogen	381.54
284.875	Oxygen	275.85
36.493	Carbon	40.57
172.293	Nitrogen	178.90
871.768		876.86

Arranging the equation in a more convenient form:

INITIAL STATE.	FINAL STATE.
2.596H ₂ O	40.57CO ₂
2.871C ₃ H ₅ (NO ₃) ₃	1.97O ₂
80.920NH ₄ NO ₃	89.45N ₂
1.000C ₁₅ H ₂₂ O ₁₀	190.77H ₂ O
1.840C ₇ H ₇ NO ₂	
	322.76 number of gas volumes

HEATS OF FORMATION OF DECOMPOSITION PRODUCTS.

	Calories.
$190.77 \times 58,100 =$	$11,083,737$
$40.57 \times 94,300 =$	$3,825,751$
$a 322.76 \times 545 =$	$175,904$
	$15,085,392$

HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.

	Calories.
$2.596 \times 69,000 =$	$179,124$
$2.871 \times 98,900 =$	$283,942$
$80.920 \times 88,050 =$	$7,125,006$
$1.000 \times 463,360 =$	$463,360$
$1.84 \times 11,300 =$	$20,792$
	$8,072,224$

$Q = 15,085,392 - 8,072,224 = 7,013,168$ calories = heat evolved by explosion of 7,786.53 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 7,786.53 GRAMS OF EXPLOSIVE.

$$c = a + bt$$

$$\begin{aligned} 6.26 \times 40.57 &= 253.9682 + 40.57 \times 0.0037t = 0.150109t \\ 5.61 \times 190.77 &= 1,070.2197 + 190.77 \times 0.0033t = .629541t \\ 4.80 \times (1.97 + 89.45) &= 438.8160 + (1.97 + 89.45) \times .0006t = .054802t \end{aligned}$$

$$\text{Total heat capacity } c = 1,763.0039 + .834502t$$

Substituting the above values for Q , a , and b in the general equation gives the value of t :

$$\begin{aligned} t &= \frac{-1,763.0039 + \sqrt{(1,763.0039)^2 + 4 \times 0.834502 \times 7,013,168}}{2 \times 0.834502} \\ t &= \frac{3,386}{1.669004} \\ t &= 2,029^\circ \text{ C} \end{aligned}$$

SPECIFIC HEATS OF SOLID SUBSTANCES AT HIGH TEMPERATURES.

Solid substances are frequent among the decomposition products of explosives, and it becomes necessary to calculate the amount of heat absorbed in raising these solids to the temperature of explosion. Most solid substances show only a small increase of specific heat with increasing temperatures, but the increment is too great to be neglected. In cases in which direct determinations have been made it has been found that the rate of increase for different substances varies somewhat. Accordingly, there can exist no simple rule for deducing the specific heat of a substance at one temperature from data that may have been obtained at some other temperature. Most substances show an increase of specific heat with increasing temperature; this increase is gradual and quite regular so long as there is no physical or chemical change in the body. Near the melting point the specific heats of many substances change rapidly, and this is especially true as regards amorphous bodies passing into the liquid state.

From an extensive study of the specific heats of solids, Kopp deduced the law that their specific heat at ordinary temperatures is additive; that is, that the molecular heat of a solid (the product of the

specific heat times the molecular weight) is equal to the sum of the atomic heats of the elements which it contains. Kopp^a found the atomic heat of most of the elements to be practically a constant (6.4), the following being the principal exceptions:

Sulphur, phosphorus, and boron.....	5.4
Fluorine.....	5.0
Silicon.....	3.8
Hydrogen.....	2.3
Oxygen.....	4.0
Carbon.....	1.8

By means of the above data the specific heats of solid compounds for which no experimental values are available may be calculated, but it is advisable to depend on the actual values obtained by experiment, where such are available.

As an example, calcium carbonate may be taken. The specific heat of calcium carbonate at ordinary temperatures has been found to be 0.203. The molecular heat of CaCO_3 would be $100 \times 0.203 = 20.3$. Calculation, by Kopp's law, gives 6.4 (atomic heat of calcium) + 1.8 (atomic heat of carbon) + 3×4 (atomic heat of 3 atoms of oxygen), the sum being 20.2. The agreement is close.

For higher temperatures it is found that the constants stated no longer hold true, and, as the temperatures for which the specific heats are desired in the calculations of explosives are in general higher than those that have been determined directly, the most convenient means of calculating specific heats appears to be to take advantage of the known increments of most elements through the range in which actual heat determinations have been made, and to assume that this same relation holds for higher temperatures. As actual determinations have been made up to a temperature of $1,600^\circ \text{C}$. in some cases, and as the temperatures for which figures are desired will usually be about $1,800^\circ$ to $2,000^\circ \text{C}$., this will be seen to involve very small chances of error.

The specific heat of most elements has been found to increase by an amount equal to 0.0003 to 0.0005 of its value at zero for each increase of 1°C ., and therefore, although not strictly accurate, the mean value 0.0004 may be used as representing a convenient approximation to the increase in specific heat of a solid for each increase of 1°C . from zero. Since in calculations, not the true specific heat, but the mean specific heat from zero to the temperature reached in the reaction is used, the value used will be one-half of the sum of the specific heats at zero and at the required temperature t . This value may be conveniently expressed by the equation

$$S_{m(0^\circ - t^\circ)} = S_0 + S_0 \times 0.0002t$$

^a Kopp, Hermann, Lieb. Ann. Suppl. 3, part 3, 1864-5, p. 289.

where $S_{m(0^{\circ}-t^{\circ})}$ equals the mean specific heat of a substance from zero to the temperature t , and where S_0 equals the specific heat of the substance at zero.

Although very few determinations of specific heats of solids at high temperatures have been made, results indicate that the increase in specific heat becomes less at high temperatures, but in all cases has a positive value.

For a considerable range on each side of $2,000^{\circ}$ C. it is believed that the use of the increment 0.0002, in the mean specific heat, for each degree of rise in temperature, gives results that are very close to the true value, and although it is clear that for lower temperatures this increment would not give high enough values, yet for such temperatures as those dealt with it would seem to give reliable results. As another example take calcium silicate. This substance, CaSiO_3 (molecular weight 116), has a specific heat at 0° C. of 0.174^a and a mean specific heat between 0° and $1,100^{\circ}$ C. of 0.2404. Its molecular heat would then be $116 \times 0.174 = 20.18$ at 0° C. and $116 \times 0.2404 = 27.88$ for the mean between 0° and $1,100^{\circ}$ C.

Calculating by Kopp's law, the molecular heat at 0° C. would be found to be 6.4 (atomic heat of calcium) + 3.8 (atomic heat of silicon) + 3×4 ($3 \times$ atomic heat of oxygen), a total of 22.2, as against the experimental value of 20.18.

Calculating the mean specific heat between 0° and $1,000^{\circ}$ C. by the formula

$$\begin{aligned} S_{m(0^{\circ}-t^{\circ})} &= S_0 + S_0 \times 0.0002t \\ S_{m(0^{\circ}-1,100^{\circ})} &= 0.174 + 0.174 \times 0.0002 \times 1,100 \\ &= 0.212, \text{ mean specific heat between } 0^{\circ} \text{ and } 1,100^{\circ} \end{aligned}$$

Then the mean molecular heat is $0.212 \times 116 = 24.62$, as compared with the experimental value of 27.88.

The application of these data to the solution of problems relative to explosions yielding solid products will now be considered.

THE MAXIMUM TEMPERATURE OF EXPLOSIVES HAVING SOLID PRODUCTS OF COMBUSTION.

In the case of explosives yielding solid products of combustion it is necessary to consider the amount of heat required to raise the temperature of such solids as are produced from the initial to the final temperature. This causes the value of c in the equation to have a somewhat different value than is the case when no solids need be considered. From the rules given in the preceding chapter the specific heat at zero of all solids entering the reaction may be calculated, this forming the a term in the equation

$$c = a + bt.$$

^a White, Walter P., Am. Jour. Science, vol. 28, Oct., 1909, p. 334.

The value of the b term is readily determined from the equation

$$S_m(90^\circ - t^\circ) = S_0 + S_6 \times 0.0002t$$

which shows that b is represented by $S_0 \times 0.0002$. Making the proper allowance for the specific heats of the solids concerned, the calculation is carried out in exactly the same manner as for explosives having no solid products of combustion. The following examples show the work in full:

Temperature of explosion of a black blasting powder.

1	2	3	4	5	6
Components.	Formula.	Composition.	Molecular weight.	Column 3 Column 4	Column 5 0.0444
Moisture.....	H ₂ O.....	0.80	18	0.0444	1.00
Sodium nitrate.....	NaNO ₃	70.57	85	.8302	18.70
Sulphur.....	S.....	10.89	32	.3403	7.66
Charcoal.....	C.....	17.74	12	1.4800	33.40

The following expression represents the composition of the explosive in gram-molecules:



SUM OF MOLECULAR WEIGHTS $\times$ NUMBER OF MOLECULES.

$$\begin{aligned} 1.00 \times 18 &= 18 \\ 18.70 \times 85 &= 1,590 \\ 7.66 \times 32 &= 245 \\ 33.40 \times 12 &= 401 \end{aligned}$$

Weight in grams of explosive considered in the calculation.....2,254

PRODUCTS OF COMBUSTION FROM 300 GRAMS POWDER.

	Grams.	Per cent.
Gas	=154.4	= 51.47
Solids	=141.5	= 47.17
Water	= 4.1	= 1.36
	<u>300.0</u>	<u>100.00</u>

SOLID PRODUCTS.

Soluble 91.2 per cent $\times 141.5 = 129.05$ grams = 43.02 per cent of total products.

Insoluble 8.8 per cent $\times 141.5 = 12.45$ grams = 4.15 per cent of total products.

47.17 per cent.

INSOLUBLE SOLIDS.

Carbon = 12.45 grams = 4.15 per cent of products.

SOLUBLE SOLIDS.

129.05 grams = 43.02 per cent of products.

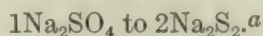
H₂S in gases = 8.24 per cent (154.4 grams gases) (S in H₂S = 94.1 per cent)

$$0.0824 \times 154.4 \times 0.941 = 11.97 \text{ grams} = \text{S in H}_2\text{S}$$

$$0.1089 \times 300 = 32.67 \text{ grams} = \text{S total in powder (300 grams)}$$

$$32.67 - 11.97 = 20.70 \text{ grams} = \text{S in solids}$$

assumed to be combined as Na_2SO_4 and Na_2S_2 in the proportion of



In $1\text{Na}_2\text{SO}_4 : 2\text{Na}_2\text{S}_2$, the proportion of S is as 1 is to 4, therefore

$$\frac{20.70}{5} = 4.14 \text{ grams S in } \text{Na}_2\text{SO}_4$$

and

$$4.14 \times 4 = 16.56 \text{ grams S in } \text{Na}_2\text{S}_2$$

$$\underline{20.70 \text{ grams S in solids}}$$

$$\frac{4.14 \times 100}{22.54} = 18.37 \text{ grams } \text{Na}_2\text{SO}_4 = 6.12 \text{ per cent of total products}$$

$$\frac{16.56 \times 100}{58.18} = 28.46 \text{ grams } \text{Na}_2\text{S}_2 = 9.49 \text{ per cent of total products.}$$

Deducting $(18.37 + 28.46)$ from the total weight of soluble solids (129.05 grams) leaves 82.22 grams Na_2CO_3 .

$$82.22 \text{ grams } \text{Na}_2\text{CO}_3 = 27.41 \text{ per cent of total products.}$$

The above quantities of solids are produced by the explosion of 300 grams of powder. Changing these values to gram-molecular quantities produced by the explosion of 2,254 grams of powder gives the following:

$$\frac{6.12 \times 2,254}{142 \times 100} = 0.97 \text{ molecules } \text{Na}_2\text{SO}_4$$

$$\frac{9.49 \times 2,254}{110 \times 100} = 1.95 \text{ molecules } \text{Na}_2\text{S}_2$$

$$\frac{27.41 \times 2,254}{106 \times 100} = 5.83 \text{ molecules } \text{Na}_2\text{CO}_3$$

$$\frac{4.15 \times 2,254}{12 \times 100} = 8.00 \text{ molecules C.}$$

GASEOUS PRODUCTS.

ANALYSES OF GASES.

	Per cent by volume.	Weight in 1 liter.	Per cent by weight.	Weight of 1 liter.
		<i>Grams.</i>		<i>Grams.</i>
CO_2	49.7	0.9766	60.81	1.965
CO	10.8	.1351	8.41	1.251
H_2S	8.7	.1324	8.24	1.522
H_2	1.8	.0016	.10	.0895
CH_4	.6	.0043	.27	.7150
N_2	28.4	.3561	22.17	1.254
	100.0	1.6061	100.00	.....

$0.5147 \times 2254 = 1160 = \text{weight in grams of gases produced by explosion of 2,254 grams of powder.}$

^a Walke, W., Lectures on explosives, pp. 147 and 151.

GRAM-MOLECULES OF GASES PRODUCED BY EXPLOSION OF 2,254 GRAMS OF POWDER.

$$\frac{60.81 \times 1,160}{44 \times 100} = 16.03 \text{ molecules CO}_2$$

$$\frac{8.41 \times 1,160}{28 \times 100} = 3.48 \text{ molecules CO}$$

$$\frac{8.24 \times 1,160}{34 \times 100} = 2.81 \text{ molecules H}_2\text{S}$$

$$\frac{0.10 \times 1,160}{2 \times 100} = 0.58 \text{ molecules H}_2$$

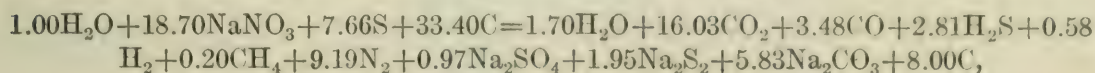
$$\frac{0.27 \times 1,160}{2 \times 100} = 0.20 \text{ molecules CH}_4$$

$$\frac{22.17 \times 1,160}{28 \times 100} = 9.19 \text{ molecules N}_2$$

LIQUID PRODUCTS.

$$\frac{1.36 \times 2,254}{18 \times 100} = 1.70 \text{ molecules H}_2\text{O}.$$

Combining the expressions found for the original explosive and for its explosion products gives the following equation which represents, in gram-molecules, the decomposition of 2,254 grams of explosive:



or, arranging in more convenient form:

INITIAL STATE.	FINAL STATE.	
1.00H ₂ O	1.70H ₂ O	} 33.99 gram-molecules of gas
18.70NaNO ₃	16.03CO ₂	
7.66S	3.48CO	
33.40C	2.81H ₂ S	
	.58H ₂	
	.20CH ₄	
	9.19N ₂	
	.97Na ₂ SO ₄	
	1.95Na ₂ S ₂	
	5.83Na ₂ CO ₃	
	8.00C	

HEATS OF FORMATION OF DECOMPOSITION PRODUCTS.

	Calories.
1.70 × 58,100 =	98,770
16.03 × 94,300 =	1,511,629
3.48 × 26,100 =	90,828
2.81 × 2,700 =	7,587
.20 × 18,900 =	3,780
.97 × 328,600 =	318,742
1.95 × 88,200 =	171,990
5.83 × 272,600 =	1,589,258
^a 34.00 × 545 =	18,530
	3,811,114

HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.

	Calories.
1.00 × 69,000 =	69,000
18.70 × 111,250 =	2,080,375
	2,149,375

^a Compensation for 34 gram-molecules of gas at constant volume.

$Q=3,811,114-2,149,375=1,661,739$ calories=heat evolved by explosion of 2,254 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 2,254 GRAMS OF EXPLOSIVE.

$$c=a+bt$$

$$1.70 \times 5.61 = 9.537 + 1.70 \times 0.0033t = 0.00561t$$

$$16.03 \times 6.26 = 100.348 + 16.03 \times .0037t = .05931t$$

$$\left. \begin{array}{l} 3.48 \\ .58 \\ 9.19 \end{array} \right\} \times 4.80 = 63.600 + \left. \begin{array}{l} (3.48) \\ (.58) \\ (9.19) \end{array} \right\} \times .0006t = .00795t$$

$$2.81 \times 6.30 = 17.703 + 2.81 \times .0005t = .00141t$$

$$.20 \times 7.10 = 1.420 + .20 \times .0005t = .00010t$$

$$.97 \times 32.83 = 31.845 + .97 \times .00657t = .00637t$$

$$1.95 \times 19.00 = 37.050 + 1.95 \times .00380t = .00741t$$

$$5.83 \times 26.08 = 152.046 + 5.83 \times .00522t = .03043t$$

$$8.00 \times 6.40 = 51.200 + 8.00 \times .00128t = .01024t$$

$$\text{Total heat capacity } c = 464.749 + .12883t$$

Substituting the above values for Q , a , and b in the general equation gives the value of t :

$$t = \frac{-464.749 + \sqrt{(464.749)^2 + 4 \times 0.12883 \times 1,661,739}}{2 \times 0.12883}$$

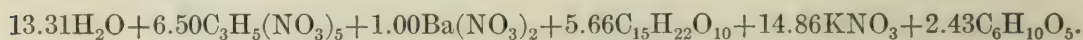
$$t = \frac{570.77}{0.25766}$$

$$t = 2,215^\circ$$

Calculation of the maximum temperature of an explosive containing an excess of carbon.

1	2	3	4	5	6
Components.	Formula.	Composition.	Molecular weight.	$\frac{\text{Column 3}}{\text{Column 4}}$	$\frac{\text{Column 5}}{0.0169}$
Moisture.....	H ₂ O.....	4.05	18	0.2250	13.31
Nitroglycerin.....	C ₃ H ₅ (ONO ₂) ₃	24.92	227	.1098	6.50
Barium nitrate.....	Ba(NO ₃) ₂	4.42	261	.0169	1.00
Wood pulp.....	C ₁₅ H ₂₂ O ₁₀	34.60	362	.0956	5.66
Potassium nitrate.....	KNO ₃	25.37	101	.2512	14.86
Starch.....	C ₆ H ₁₀ O ₅	6.64	162	.0411	2.43
		100.00			

The following expression represents the composition of the explosive in gram-molecules:



SUM OF MOLECULAR WEIGHTS $\times$ NUMBER OF MOLECULES.

$$13.31 \times 18 = 239.60$$

$$6.50 \times 227 = 1,475.50$$

$$1.00 \times 261 = 261.00$$

$$5.66 \times 362 = 2,048.92$$

$$14.86 \times 101 = 1,500.86$$

$$2.43 \times 162 = 393.66$$

Weight in grams of explosive considered in the calculation.....5,919.54

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EXPLOSIVE.

	GRAMS.
Gas	= 130.3
Solid	= 49.0
Liquid	= 12.4
	191.7
	8.3 (loss)
	200.0

Let it be assumed that the above loss of products is H_2O , then

Total H_2O	= 12.4 + 8.3 = 20.7 grams = 10.35 per cent of products
Gas	= 130.3 grams = 65.15 per cent of products
Solid	= 49.0 grams = 24.50
	200.0 grams = 100.0

SOLID PRODUCTS.

Insoluble 23.9 per cent $\times 49 = 11.71$ grams = 5.86 per cent of total products
 Soluble 76.1 per cent $\times 49 = 37.29$ grams = 18.64 per cent of total products

INSOLUBLE SOLIDS.

4.42 per cent $\text{Ba}(\text{NO}_3)_2 = 8.84$ grams $\text{Ba}(\text{NO}_3)_2$ in 200 grams powder
 $= 6.71$ grams $\text{BaCO}_3 = 3.35$ per cent of total products.

Deducting 6.71 grams BaCO_3 from 11.71 grams total insoluble solids leaves 5.00 grams assumed to be free carbon = 2.5 per cent of total products.

SOLUBLE SOLIDS.

50.74 grams = KNO_3 in 200 grams powder ($0.2537 \times 200 = 50.74$ grams)
 37.29 grams soluble solids assumed to be $\text{K}_2\text{CO}_3 + \text{KHCO}_3$
 x grams $\text{K}_2\text{CO}_3 = 0.565 x$ grams K
 $(37.29 - x)$ grams $\text{KHCO}_3 = 0.39 (37.29 - x)$ grams K
 50.74 grams $\text{KNO}_3 = 0.386 \times 50.74$ grams K = 19.585 grams K
 $0.565x + 0.39 (37.29 - x) = 19.585$
 $0.565x + 14.54 - 0.39x = 19.585$
 $0.175x = 5.04$
 $x = 28.8$ grams $\text{K}_2\text{CO}_3 = 14.4$ per cent of total products
 $37.29 - x = 8.49$ grams $\text{KHCO}_3 = 4.25$ per cent of total products

Changing the above quantities of solids to gram-molecular quantities produced by explosion of 5,919.54 grams of explosive gives the following:

$$\frac{3.33 \times 5,919.54}{197 \times 100} = 1.00 \text{ molecules } \text{BaCO}_3$$

$$\frac{2.5 \times 5,919.54}{12 \times 100} = 12.33 \text{ molecules C}$$

$$\frac{14.4 \times 5,919.54}{138 \times 100} = 6.17 \text{ molecules } \text{K}_2\text{CO}_3$$

$$\frac{4.25 \times 5,919.54}{100 \times 100} = 2.52 \text{ molecules } \text{KHCO}_3$$

GASEOUS PRODUCTS.

ANALYSIS OF GASES.

	Per cent by volume.	Weight in 1 liter.	Per cent by weight.	Weight of 1 liter.
CO ₂	18.9	0.371	36.52	1.965
CO.....	36.3	.454	44.69	1.250
H ₂	29.1	.026	2.56	.0895
N ₂	9.9	.124	12.20	1.254
CH ₄	5.8	.041	4.03	.715
		1.016	100.00	

$$\frac{65.15 \times 5,919.54}{100} = 3,856 = \text{weight in grams of gases produced by explosion of 5,919.54 grams of explosive.}$$

$$\frac{3,856 \times 36.52}{44 \times 100} = 32.01 \text{ molecules CO}_2$$

$$\frac{3,856 \times 44.69}{28 \times 100} = 61.54 \text{ molecules CO}$$

$$\frac{3,856 \times 2.56}{2 \times 100} = 49.36 \text{ molecules H}_2$$

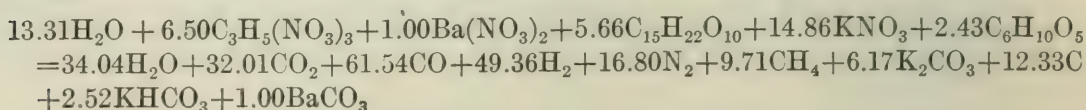
$$\frac{3,856 \times 12.2}{28 \times 100} = 16.80 \text{ molecules N}_2$$

$$\frac{3,856 \times 4.03}{16 \times 100} = 9.71 \text{ molecules CH}_4$$

LIQUID PRODUCTS.

$$\frac{10.35 \times 5,919.54}{18 \times 100} = 34.04 \text{ molecules H}_2\text{O.}$$

Combining the expressions found for the original explosive and for its explosion products gives the following equation, which represents in gram-molecules the decomposition of 5,919.54 grams of explosive:



or, rearranging:

INITIAL STATE.	FINAL STATE.
13.31H ₂ O	34.04H ₂ O
6.50C ₃ H ₅ (NO ₃) ₃	32.01CO ₂
1.00Ba(NO ₃) ₂	61.54CO
5.66C ₁₅ H ₂₂ O ₁₀	49.36H ₂
14.86KNO ₃	16.80N ₂
2.43C ₆ H ₁₀ O ₅	9.71CH ₄
	12.33C
	6.17K ₂ CO ₃
	2.52KHCO ₃
	1.00BaCO ₃

} 203.46 gram-molecules of gas.

HEATS OF FORMATION OF DE- COMPOSITION PRODUCTS.	HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.
Calories.	Calories.
$34.04 \times 58,100 = 1,977,724$	$13.31 \times 69,000 = 918,390$
$32.01 \times 91,300 = 3,018,543$	$6.50 \times 98,900 = 642,850$
$61.54 \times 26,100 = 1,606,194$	$1.00 \times 228,400 = 228,400$
$9.71 \times 18,900 = 183,519$	$5.66 \times 463,360 = 2,622,617$
$6.17 \times 281,100 = 1,734,387$	$14.86 \times 119,500 = 1,775,770$
$2.52 \times 233,300 = 587,916$	$2.43 \times 225,900 = 548,937$
$1.00 \times 285,600 = 285,600$	
$a \ 203.46 \times 545 = 110,886$	
	6,736,964
9,504,769	

$Q = 9,504,769 - 6,736,964 = 2,767,805$ calories = heat evolved by explosion of 5,919.54 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 5,919.54 GRAMS OF EXPLOSIVE.

$$c = a + bt$$

$$\begin{array}{rcl}
 34.04 \times 5.61 & = & 190.96 + 34.04 \times 0.0033t = 0.112332t \\
 32.01 \times 6.26 & = & 200.38 + 32.01 \times .0037t = .118437t \\
 61.54 & & (61.54) \\
 49.36 & \times 4.80 & = 612.96 + (49.36) \times .0006t = .076620t \\
 16.80 & & (16.80) \\
 9.71 \times 7.10 & = & 68.94 + 9.71 \times .0005t = .004855t \\
 6.17 \times 28.428 & = & 175.40 + 6.17 \times .00568t = .035046t \\
 2.52 \times 20.600 & = & 51.71 + 2.52 \times .00416t = .010483t \\
 1.00 \times 21.670 & = & 21.67 + 1.00 \times .00433t = .004330t \\
 12.33 \times 6.4 & = & 78.91 + 12.33 \times .00128t = .015782t
 \end{array}$$

$$\text{Total heat capacity, } c, = 1,400.93 + .377885t$$

Substituting the above values for Q , a , and b in the general equation gives the value of t .

$$t = \frac{-1,400.93 + \sqrt{(1,400.93)^2 + 4 \times 0.377885 \times 2,767,805}}{2 \times 0.377885}$$

$$t = \frac{1,078}{0.75577}$$

$$t = 1,426^\circ$$

COMPARISON OF TWO EXPLOSIVES.

The two following explosives contain the same constituents in very nearly the same proportions; one passes and the other does not pass a test at the Pittsburgh testing station. Comparison of the two shows how small a difference in composition may determine whether or not an explosive will pass a required test.

^a Compensation for 203.46 gram-molecules of gas at constant volume.

The chemical composition of the explosive that passed the test is as follows:

Moisture.....	4.70
Nitroglycerin.....	24.61
Sodium nitrate.....	44.22
Calcium carbonate.....	.81
Magnesium carbonate.....	2.09
Sulphur.....	.67
Coal.....	22.90
	100.00

The constituent noted as "coal" in this powder is a mixture of coke with a natural coal, and by determination of its volatile matter its composition is assumed to be expressed by the formula:



The products of combustion from this explosive were as follows:

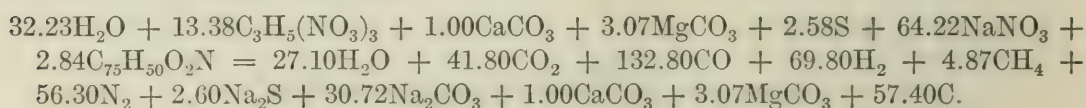
Gases.....	59.55
Solids.....	36.50
Liquid (H ₂ O).....	3.95
	100.00

The composition of the gaseous products, in parts by volume, were as follows:

CO ₂	13.7
CO.....	43.5
H ₂	22.8
CH ₄	1.6
N ₂	18.4
	100.0

The solid products consisted of calcium carbonate, magnesium carbonate, carbon, sodium sulphide, and sodium carbonate.

The decomposition of the explosive was assumed to be represented by the following equation:



By calculating from the above equation the maximum temperature of explosion, in the same manner as has been done in previous cases, there is obtained:

$$Q=6,879,599 \text{ calories} \quad c=2,982.214+0.66025t$$

$$t = \frac{-2,982.214 + \sqrt{(2,982.214)^2 + 4 \times 0.66025 \times 6,879,599}}{2 \times 0.66025}$$

$$t=1,631^\circ$$

The analysis of the explosive that did not pass the tests was as follows:

Moisture.....	3.78
Nitroglycerin.....	18.14
Sodium nitrate.....	56.96
Calcium carbonate.....	.92
Magnesium carbonate.....	2.67
Sulphur.....	.36
Coal.....	17.17
	100.00

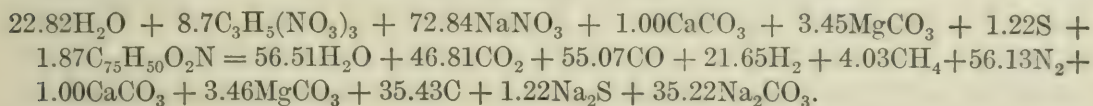
The coal mixture in this powder was identical with that of the other powder just calculated. The products of decomposition from this explosive were as follows:

	Per cent.
Gases.....	48.55
Solids.....	42.10
Liquid (H ₂ O).....	9.35
	100.00

The composition of the gaseous products in percentage by volume was as follows:

	Per cent.
CO ₂	25.5
CO.....	30.0
H ₂	11.8
CH ₄	2.2
N ₂	30.5
	100.0

The solid products were: Calcium carbonate, magnesium carbonate, free carbon, sodium sulphide, and sodium carbonate, as before, and the decomposition of the explosive was assumed to be as follows:



By calculating from this equation the maximum temperature of explosion, there is obtained:

$$Q=8,322,270 \text{ calories.} \quad c=2,524.934+0.687582t$$

$$t = \frac{-2,524.934 + \sqrt{(2,524.934)^2 + 4 \times 0.687582 \times 8,322,270}}{2 \times 0.687582}$$

$$t=2,098^\circ$$

It is interesting to note that the difference of about 500° C. in the maximum temperature shown by these two explosives is enough to determine the success of one and the failure of the other in the tests required at the Pittsburgh station. It seems probable in the case of

some explosives that pass all but one of the tests at the Pittsburgh station, that a change in composition effecting as slight a reduction of flame temperature as 100° or 200° C. might put them upon the permissible list, since it is probable that a very small variation in flame temperature is the determining factor. One should not infer from this that it is desirable that explosives should pass the requirements by the narrowest possible margin of flame temperature. An explosive whose flame temperature is quite low can probably be used in larger amounts without grave danger than can an explosive whose flame temperature is higher. But explosives having desirable properties may, as regards flame temperature, approach close to the ignition limit. In the case of such explosives it should always be possible by the selection of suitable means to so reduce the flame temperature as to enable the explosive to pass the tests.

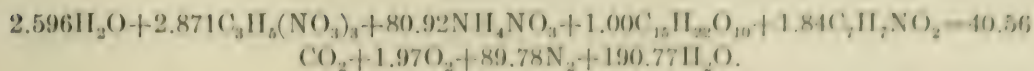
RESULTS OF DIRECT CALORIMETRIC DETERMINATIONS.

In the methods of calculation already shown it has been assumed that no knowledge was available in regard to the explosive reaction other than the analysis of the original explosive and that of the resulting products.

By firing a charge of an explosive in a suitable calorimetric bomb it is possible to obtain a direct value for Q , the amount of heat evolved in the chemical reaction taking place at the moment of explosion, and the value of Q has been so determined for a number of explosives. A comparison of the values thus obtained with those found by calculation is of interest; it shows that the results obtained by calculation are in very close agreement with the values obtained by direct determination.

In order that the results from direct determinations may be comparable with those obtained by calculation, one should remember that the direct readings in a calorimetric bomb must be corrected for the amount of heat set free in the condensation to liquid water of all the water vapor present. The reactions involved in any explosion take place at a temperature higher than that which would permit the condensation to liquid water of the water formed, but the calorimetric bomb is itself immersed in water, and the resulting products of explosion are maintained at a temperature lower than that at which gaseous water is stable. Accordingly, all of the water vapor formed occurs in the products as liquid water, and the amount of heat evolved, as shown by the calorimeter, is higher by the value representing the latent heat of evaporation of this water. As an example of the calculation of the temperature of explosion, as determined by direct calorimetric readings, the case of the ammonium nitrate explosive previously calculated on pages 34 to 36

may be taken. The reaction considered in this explosive was as follows:



By direct reading of the calorimeter it was found that 1,245 calories were evolved per gram of explosive taken, the water being liquid. As the amount of H_2O in each gram of total products is found to be 0.441 gram, and as the change from gaseous water to liquid water evolves 10,900 calories for each gram-molecule of water taken (18 grams), the correction in this example for liquid water is:

$$\frac{10900 \times .441}{18} = 267.6 \text{ calories per gram.}$$

The evolution of heat being 1,245 calories per gram of material, and the correction being 267.6 calories per gram, there results a net evolution of heat per gram of reacting substance of 977.4 calories, and for the 7,786 grams of material in the reaction,

$$Q = 7,610,036 \text{ calories.}$$

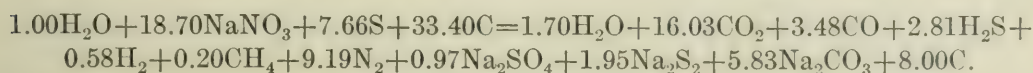
Calculation from this value gives:

$$t = \frac{-1,764.5253 + \sqrt{(1,764.5253)^2 + 4 \times .834663 \times 7,610,036}}{2 \times 0.834663} \\ t = 2142^\circ$$

By calculation from the analysis of the explosive, the value of Q was found to be 7,012,437. The value of t from this is:

$$t = \frac{-1,764.5253 + \sqrt{(1,764.5253)^2 + 4 \times 0.834663 \times 7,012,437}}{2 \times 0.834663} \\ t = 2028^\circ$$

Proceeding in a similar manner with the black powder calculated on pages 39 to 42 the following equation is obtained:



By the calorimeter it is found that 789.4 calories per gram are evolved (water liquid).

Each gram of products contains 0.0136 gram of H_2O , the correction for which (from liquid to gas) is:

$$\frac{10900 \times 0.0136}{18} = 8.23 \text{ calories per gram of products}$$

Applying this correction gives $789.4 - 8.23 = 781.2$ calories = evolution of heat per gram of products (water gaseous), and for the 2,254 grams of material in the reaction,

$$Q = 1,760,825 \text{ calories}$$

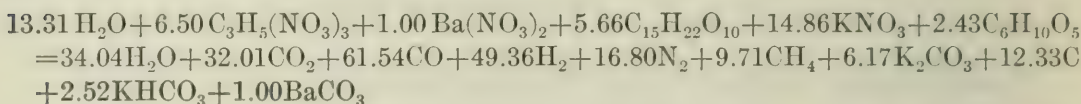
then

$$t = \frac{-464.749 + \sqrt{(464.749)^2 + 4 \times 0.12883 \times 1,760,825}}{2 \times 0.12883}$$

$$t = 2,310^\circ$$

In the calculation (p. 42) Q was found from analysis to be 1,661,739 calories and $t = 2,215^\circ$.

For the explosive calculated on pages 42 to 45, the following reaction is obtained.



Heat evolved per gram, from the calorimeter reading, = 570.7 calories (H_2O liquid).

$$1 \text{ gram products} = 0.1035 \text{ gram H}_2\text{O}$$

Correction for H_2O liquid to H_2O gaseous equals

$$\frac{10900 \times 0.1035}{18} = 62.67 \text{ calories per gram}$$

Then

$$570.7 - 62.67 = 508.03 \text{ calories evolved per gram of products (water gaseous)}$$

and for the 5,920 grams of material in the reaction,

$$Q = 3,007,537 \text{ calories}$$

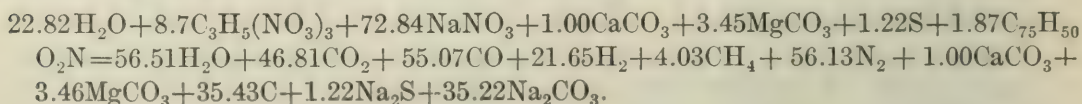
and

$$t = \frac{-1,400.93 + \sqrt{(1,400.93)^2 + 4 \times 0.377885 \times 3,007,557}}{2 \times 0.377885}$$

$$t = 1,522^\circ$$

The value of Q calculated from the analysis was 2,767,805 calories, and $t = 1,426^\circ$ (p. 45).

The calorimeter test of the explosive calculated on page 47 furnishes still another example. In this case there was an evolution of 827.6 calories per gram (H_2O liquid); the reaction being:



Hence

$$827.6 - \frac{10,900 \times 0.0935}{18} = 827.6 - 56.2 = 771.4 \text{ calories per gram (H}_2\text{O gaseous)}.$$

For the total material in the reaction (10,878 g.) $Q = 771.4 \times 10,878 = 8,391,289$ calories.

Then

$$t = \frac{-2,524.934 + \sqrt{(2,524.934)^2 + 4 \times 0.687582 \times 8,391,289}}{2 \times 0.687582}$$

$$t = 2110^\circ$$

By the calculation from analysis was found,

$$Q = 8,322,270 \text{ calories}$$

$$t = 2,098^\circ.$$

PRACTICAL METHODS OF REDUCING THE FLAME TEMPERATURES OF EXPLOSIVES.

Among the methods which have been used for reducing the flame temperature of explosives, the following list seems to include all that are at present of importance:

(a) The addition of an excess of carbon, for the purpose of reducing the amount of carbon dioxide formed.

(b) The addition of free water.

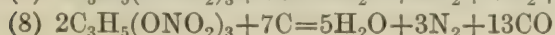
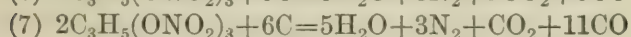
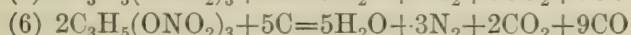
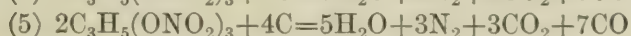
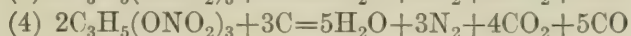
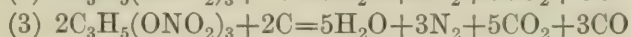
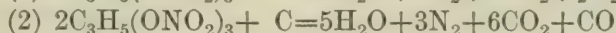
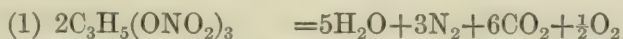
(c) The addition of solids holding water of crystallization.

(d) The addition of inert materials, such as fine sand, clay, etc.

(e) The addition of very volatile salts.

THE ADDITION OF AN EXCESS OF CARBON.

In regard to the first of the above methods, it has already been shown in the remarks on the thermochemistry of carbon monoxide and carbon dioxide (pp.19-21) that little reduction in temperature is brought about solely through the conversion of carbon dioxide to carbon monoxide, but that when this operation takes place in the presence of other materials having fairly high specific heats, a very decided reduction in temperature results. The low specific heat of carbon monoxide prevents a reduction in temperature by the conversion of carbon dioxide into carbon monoxide, but in all cases where other materials are produced (and in all commercial explosives other gases are formed with carbon dioxide and carbon monoxide), this reaction may result in pronounced lowering of temperature. The maximum temperature of explosion of nitroglycerin has already been shown to be $3,155^\circ \text{C}$. To show the manner in which the conversion of the carbon dioxide produced in the explosion of nitroglycerin into carbon monoxide would affect the maximum temperature of explosion, the maximum temperatures in the following reactions were calculated:



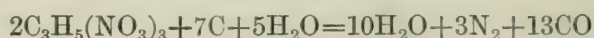
The values obtained in each case were as follows:

Effect of added carbon in lowering flame temperature of nitroglycerin.

	Total calories	Calories per gram	Calories per liter	Liters per gram	t°
Reaction 1.....	666,402	1,468	2,052	0.715	3,155
Reaction 2.....	692,775	1,486	2,062	.721	3,201
Reaction 3.....	651,220	1,362	1,817	.750	3,121
Reaction 4.....	609,665	1,244	1,601	.777	3,033
Reaction 5.....	568,110	1,131	1,409	.803	2,936
Reaction 6.....	526,555	1,024	1,237	.828	2,828
Reaction 7.....	485,000	922	1,082	.852	2,709
Reaction 8.....	443,445	824	942	.874	2,577

In the explosion of nitroglycerin no carbon monoxide is produced. All of the carbon present in the nitroglycerin is converted into carbon dioxide. By the addition of successive quantities of carbon the formation of this carbon dioxide is prevented, double the volume of carbon monoxide in each case resulting. Comparison of the maximum temperatures produced shows that the addition of the first gram-molecule of carbon gave an increase in temperature, the explosion of nitroglycerin alone reaching 3,155° C. and that of the mixture $2\text{C}_3\text{H}_5(\text{NO}_3)_3 + \text{C}$, 3,201°. The reason for this is found in the free oxygen produced in the decomposition of nitroglycerin, this oxygen combining with the carbon to form carbon dioxide, and thus bringing about an increase in the temperature produced by the reaction. When the columns of figures are examined in detail, it will be seen that the calories evolved per liter of gas are more than twice as great in the case of nitroglycerin alone as when the nitroglycerin is mixed with 7C. The temperature, however, because of the low specific heat of carbon monoxide, does not undergo a corresponding change. The difference between the explosion temperature of pure nitroglycerin and that of nitroglycerin + 7C is less than 600°.

When additional water is present during the reaction a much greater reduction in temperature is brought about, as will be seen from the following example:



Heats of formation of decomposition
products.

Calories.
 $10 \times 58,100 = 581,000$
 $13 \times 26,100 = 339,300$
 $^a 26 \times 545 = 14,170$

 934,470

Heats of formation of original
constituents.

Calories.
 $2 \times 98,900 = 197,800$
 $5 \times 69,000 = 345,000$

 542,800

$$Q = 934,470 - 542,800 = 391,670 \text{ calories.}$$

^a Compensation for 26 gram-molecules of gas.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS.

$$c=a+bt$$

$$10\text{H}_2\text{O}=10\times 5.61=56.10+10\times .0033t=0.0330t$$

$$3\text{N}_2+13\text{CO}=16\times 4.80=76.80+16\times .0006t=.0096t$$

$$\text{Total heat capacity, } c, =132.90+.0426t$$

Hence,

$$t=\frac{-132.90+\sqrt{(132.90)^2+4\times 0.0426\times 391,670}}{2\times .0426}$$

$$t=157.62$$

$$t=0.0852$$

$$t=1,850^\circ$$

Hence the addition of an excess of carbon to any explosive in the explosion of which considerable amounts of carbon dioxide are produced, in order to cause the formation of carbon monoxide in the place of carbon dioxide, is an efficient means of reducing the flame temperature, and the efficiency of the method is proportional to the specific heats of the products of combustion of the explosives.

THE ADDITION OF FREE WATER.

The high specific heat of water makes it a desirable constituent of the products of combustion of an explosive. At the temperature of explosion, water performs an important function in increasing the gaseous volume of the explosive. As the water is present in the explosive in a free condition, the number of calories that represent the change from liquid water to gaseous water must be absorbed from the heat produced by the explosive, and in this way a further reduction in the temperature is brought about. Water, up to 1.5 or 2 per cent, is present in nearly all explosives as an accidental impurity due to the hygroscopicity of certain constituents, particularly sodium nitrate and wood pulp. Water, up to 10 or 12 per cent, is found in certain classes of explosives intended for use in the presence of explosive-gas mixtures. In these classes the excess of water over the 1.5 to 2 per cent normally present, represents an intentional addition of water for the purpose of reducing flame temperature. The amount of water which can be added during manufacture to any explosive mixture depends upon the absorptive capacity and the consistency of the finished explosive.

The composition of an explosive may be such as to make inadvisable the addition of the amount of free water which calculations show to be necessary to properly reduce the flame temperature. In cases of this sort, the use of water chemically combined as water of crystallization may be resorted to, since water in chemical combination in crystals can be added to an explosive mixture in greater quantities than would ever be advisable with free water. The following considerations will show the amount of energy that is required to

change free water in an explosive to gas at the temperature of explosion:

The conversion of liquid water at zero to gaseous water at zero requires the absorption of 10,900 calories for each gram-molecule. If the reaction occurs under constant conditions of volume, as is usually assumed in all cases of explosive decomposition, the value will be 545 calories less, or 10,355 calories.

The mean molecular heat of gaseous water is

$$c=5.61+0.0033t$$

Since $t = \frac{Q}{c}$ and $c = a + bt$, the law expressing the amount of heat required to raise a gas to a given temperature, t , under conditions of constant volume, is

$$Q=at+bt^2.$$

By the aid of these data the number of calories that will be absorbed in any explosive by the addition of a given amount of water, may be calculated, and the number of calories required to raise the temperature of a given amount of water vapor may also be determined. If the raising of 1 gram-molecule (18 grams) of liquid water from 0° to $2,000^\circ$ C. be taken as an example, the figures will be as follows:

The conversion of 1 gram-molecule of liquid water to gaseous water, at constant volume, requires 10,355 calories. Therefore Q , the quantity of heat required to convert 1 gram-molecule of liquid water at 0° C. to gaseous water at $2,000^\circ$ C., will be:

$$10,355 \text{ calories} + (5.61 \times 2,000 + 0.033 \times 4,000,000) = 34,775 \text{ calories}$$

As this is for 18 grams of water, it will be seen that for each gram of liquid water present in any explosive, 1,932 calories will be required to raise the temperature of this water from 0° to $2,000^\circ$ C. By calculating in this way, the approximate amount of water required in an explosive to reduce its flame temperature to a safe limit may be ascertained.

THE ADDITION OF SOLIDS HOLDING WATER OF CRYSTALLIZATION.

Free water affects the consistency of explosives. If present in considerable quantity with nitroglycerin, it causes the latter to exude from the cartridges of the explosive. Water combined as water of crystallization does not have either of these disadvantages. Moreover, it possesses an advantage in the fact that heat is absorbed in breaking the union between the salt and the water, and in this way an additional absorption of heat is brought about. An example of salts holding water of crystallization that are suitable for use in explosives is magnesium sulphate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$.

This material, commercially known as Epsom salt, is a white crystalline solid, neither markedly efflorescent nor deliquescent under ordinary atmospheric conditions. Calculation from its formula shows that it contains 51.22 per cent water. When 1 gram-molecule of magnesium sulphate unites with 7 molecules of water to form Epsom salt, 24,080 calories are evolved. Therefore, in the breaking up of the salt, allowance must be made for this amount of heat, as well as for that absorbed in converting the liquid water to gaseous water and in raising the temperature of the water and the solid residue to the temperature of explosion. The total heat absorbed for 1 gram-molecule of the Epsom salt is therefore:

	Calories.
Heat of hydration of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	= 24,080
Heat of vaporization of $7\text{H}_2\text{O}$, at constant volume ($7 \times 10,335$)..	= 72,485
Heat required to raise $7\text{H}_2\text{O}$ to $2,000^\circ$ ($Q=at+bt^2$).....	= 170,940
Heat required to raise MgSO_4 to $2,000^\circ$ ($S_{m(0^\circ-t^\circ)}=S_0+S_0 \times .0002t$)	= 75,600
	343,105

As this result is for 1 gram-molecule, or 246 grams, of Epsom salt, it follows that the quantity of heat absorbed by 1 gram will be 1,394 calories.

The following table shows for a number of crystalline salts the percentage of water, the heat required to raise the temperature of 1 gram-molecule of the material from 0° to $2,000^\circ \text{C.}$, the heat required to raise 1 gram, and the volume of water vapor at $2,000^\circ \text{C.}$ (constant pressure), resulting from 1 gram of the crystallized salt:

Cooling properties of several crystalline salts.

Formula.	Per cent of H_2O .	Calories per gram-molecule (0° - $2,000^\circ \text{C.}$).	Calories per gram (0° - $2,000^\circ \text{C.}$).	Volume of H_2O in liters per gram at $2,000^\circ \text{C.}$
$\text{Al}_2\text{K}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$	45.57	1,229,232	1,297	4.722
$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$	48.81	922,950	1,386	5.057
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	43.90	344,554	1,200	4.548
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	51.22	343,105	1,394	5.307
$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	55.90	458,895	1,425	5.792
$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	62.93	441,063	1,542	6.520
$(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$	12.67	200,070	1,409	1.313

THE ADDITION OF INERT MATERIALS.

Fire clay, sand, and other materials of a like nature are sometimes added to explosive material, in which they act as a filler or substance to give weight and also exercise an influence in regard to the reduction of flame temperature. From a critical study of the properties of these materials it does not seem that decided advantages are

gained by their use for the purpose of lowering the flame temperature, since the result achieved is certainly far less than is the case when either salts holding water of crystallization or very volatile substances are employed. Some data as to this low efficiency in regard to the reduction of flame temperature may be gained by taking a typical substance, silicon dioxide, and calculating the number of calories required to raise this material to the temperature of $2,000^{\circ}\text{C}$.

$$S_0 \text{ for SiO}_2 = 0.191.$$

From this it appears that only 534.8 calories are required to raise the temperature of 1 gram of silicon dioxide from 0° to $2,000^{\circ}\text{C}$. When this value is compared with 1,394 calories required, through the same temperature range, for magnesium sulphate, or with 1,200 calories for zinc sulphate, etc., it will be seen that a small quantity of one of these hydrated salts will give all the advantages obtained by the use of a larger quantity of an inert substance, while at the same time the gaseous matter produced from the hydrated salt will assist the explosive action of the material.

THE ADDITION OF VERY VOLATILE SALTS.

Any substance, solid at ordinary temperatures and completely gaseous at the temperature reached during the reaction of an explosive, forms a means of reducing the maximum flame temperature produced by explosives. Heat is absorbed in raising the solid material to its temperature of fusion. Heat is also absorbed in the process of fusion and in heating the fused material to the temperature of volatilization. A further quantity of heat is absorbed in the volatilization of the material and the heating of the gases thus produced.

It is unfortunate that thermochemical data regarding the temperature of fusion and latent heats of volatilization of common substances are as yet so incomplete. Of the substances that might possibly be used in explosives for the purpose mentioned no note whatever is made in any of the tables so far found of thermochemical data in regard to their latent heats of volatilization, and in only one or two cases were estimates found in regard to the temperatures at which these changes occur. In the case of sodium chloride, a material that has been used with considerable success in the past few years as a component of explosive mixtures and is to-day the volatile salt most widely used for reducing the flame temperature of explosives, no references to either the latent heat of fusion or the latent heat of volatilization have been found in the pertinent literature. Therefore complete calculations of explosives involving sodium chloride can not be made with great accuracy.

As an example of the effects produced by relatively small additions of sodium chloride, an explosive of the following composition may be taken:

	Per cent.
Nitroglycerin.....	25.0
Sodium nitrate.....	30.5
Wood meal.....	39.5
Potassium bichromate.....	5.0
	100.0

The charge limit of this explosive when tested in coal dust and air was found to be 150 grams. The composition of the explosive was then altered by the addition of sodium chloride, this material being used in place of potassium bichromate in the powder first mentioned. The composition of the new explosive was:

	Per cent.
Nitroglycerin.....	25.0
Sodium nitrate.....	30.0
Wood meal.....	38.0
Sodium chloride.....	7.0
	100.0

The charge limit of this explosive was found to be more than four times as great as that of the first explosive mentioned, and charges up to 635 grams were repeatedly fired into coal dust mixtures without causing ignition.

Sodium chloride has been added to a number of explosives, and the results have been in general to effect an increase in the charge limit and a lowering of the flame temperature.

In these calculations the influence of different compounds has been considered only in relation to the thermochemical influence that every material will have upon the explosive mixture. Remembering the effects which some of these materials have when mixed with other ingredients used in explosives, one sees that some of these compounds which seem very advantageous when their thermochemical properties alone are considered can not be mixed with other substances commonly used in explosives. For example, crystals of sodium sulphate have 10 molecules of water of crystallization and 55.9 per cent of the weight of the crystallized substance is water. This substance might seem to be a desirable one to add to explosives for the purpose of introducing water of crystallization, and its cheapness might seem to make it particularly desirable. But sodium sulphate is an efflorescent salt, that is, one that gives off its water of crystallization with great readiness. Were this substance to be used as a constituent of an explosive containing ammonium nitrate, sodium nitrate, or other deliquescent material,

the crystals of sodium sulphate would gradually lose most of their moisture, and the deliquescent salts would absorb this moisture and become wet. It is accordingly evident that in the preparation of an explosive no efflorescent salts should be used if any deliquescent material is to be used in the composition of that particular explosive.

In the class of incompatibles, as substances are named that can not be mixed together without chemical action, are acid salts and nitroglycerin. Nitroglycerin becomes unstable in the presence of free acid, and any substance that is itself acid or which may become acid should not be mixed with nitroglycerin nor added to explosives containing nitroglycerin. A nitroglycerin explosive containing a substance that might slowly develop acidity would undoubtedly, in the course of time, become unsafe through the gradual decomposition of the nitroglycerin. The formation of nitrous fumes increases the rapidity of decomposition of nitroglycerin and brings about conditions that may very readily result in an explosion.

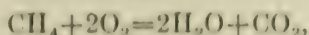
Ammonium nitrate and potassium chlorate should not be used together in explosives. Although a mixture of these two materials is not dangerous as long as it is thoroughly dry, yet in the presence of moisture, changes occur that lead to the evolution of chloric acid and other decomposition products. Explosives containing potassium chlorate and ammonium nitrate have been found to be spontaneously inflammable, and several accidents have resulted from their use.

A complete list of incompatibles can not be given, but the general rule is that no substances, which, either dry or in the presence of a small amount of water, can react with one another at ordinary temperatures, ought to be used together in an explosive mixture. Substances that do not appear to react under ordinary conditions show evidences of chemical action in the presence of small amounts of moisture, and as it is never certain that an explosive mixture can be kept fully protected, compounds that show such a reaction should be carefully avoided.

HEATS OF FORMATION.

If no direct determinations have been made of the heat of formation of a combustible organic body, a very close approximation to the true value may be reached by calculation from the known heat of combustion of the material. By complete combustion the substance is resolved into carbon dioxide, nitrogen, water vapor, etc. It is evident that the heat of formation of the body from its elements will be the difference between the sum of the heats of formation of the products resulting from its complete combustion, and the heat of combustion of the material itself. As a simple example of this

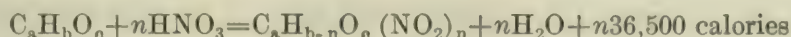
method of calculation methane may be taken. Methane, burning to H_2O and CO_2 , according to the reaction



produces 13,343 calories per gram of methane.^a Accordingly, the heat of combustion of 1 gram-molecule of methane will be $16 \times 13,343$ calories, or 213,488 calories. The heat of formation of 1 gram-molecule of CO_2 is 94,300, and the heat of formation of 2 gram-molecules of water is $2 \times 69,000$ calories (the water being liquid). The heat of formation of methane is the difference between 213,488 calories and $94,300 + 2 \times 69,000$, which is 18,812 calories.

Tables of heats of formation give 18,900 calories (Berthelot) as the heat of formation of methane, a value that is in substantial accord with the figure just deduced.

If the heat of formation of an organic body is known, but the heats of formation of its nitro derivatives or its organic nitrates have not been determined, the rule given by Berthelot is a convenient one for determining these values. He found that the action of nitric acid upon an organic body, with the entrance of the NO_2 group, evolved about 36,500 calories. As all the other products of reaction have constant heats of formation, this change may be expressed in an equation as follows:



As the heat of formation of nitric acid is 41,500 calories, and that of liquid water 69,000 calories, the equation should be so written as to state that the heat of formation of the original organic body plus 41,500 calories, equals the heat of formation of the nitro body, plus 69,000 calories, minus 36,500 calories.

Then

$$x + 41,500 \text{ calories} = x + y + 69,000 \text{ calories} - 36,500 \text{ calories}$$

Eliminating x gives:

$$y = 9,000 \text{ calories}$$

This indicates that 9,000 calories are evolved when one NO_2 group is introduced into an organic body. This fact may be expressed as a general rule covering organic bodies, as follows:

$$K = L + n \times 9,000 \text{ calories}$$

where K is the heat of formation of the organic body, L is the heat of formation of the nitro-substitution body, and n is the number of nitro groups introduced.

In a similar way the heat of formation of an organic nitrate may be determined when the heat of formation of the corresponding

^a According to Berthelot the heat of burning of 1 gram $\text{CH}_4 = 13,343$ calories.

simple body is known, and this may be expressed in general as follows:

$$L=K-n\times 22,400 \text{ calories}$$

where K is the heat of formation of any organic body, L is the heat of formation of its nitrate, and *n* is the number of nitrate groups that have been introduced.

In both of the cases above-mentioned it should be remembered that the physical state of the nitrate or nitro body must be the same as that of the original organic body, since the reactions take account only of the heat evolved in the chemical changes that take place upon the conversion of the original body into the final body. No account is taken of any change of state that occurs in the meantime, as, for example, a liquid organic body forming a solid nitro body.

As an example of the calculation of the heat of formation of a nitro body, the following may be taken:

The heat of formation of benzene (C₆H₆) was found to be -4,100 calories (Berthelot). By the rule just given the heat of formation of mono-nitrobenzene should be -4,100 calories +9,000 calories =4,900 calories. A direct determination of the heat of formation of mono-nitrobenzene gave the value 5,100 calories (Berthelot). The theoretical calculation agrees within 200 calories with the value determined by experiment.

TABLES OF USE IN THERMOCHEMICAL CALCULATIONS.

The following tables contain data of value to the explosives chemist.

TABLE 1.—Atomic weights, expressed in round numbers, of the elements likely to be met with in the manufacture of explosives.

Element.	Symbol.	Atomic weight.	Element.	Symbol.	Atomic weight.
Aluminum.....	Al	27	Magnesium.....	Mg	24
Antimony.....	Sb	120	Manganese.....	Mn	55
Arsenic.....	As	75	Mercury.....	Hg	200
Barium.....	Ba	137	Nitrogen.....	N	14
Calcium.....	Ca	40	Oxygen.....	O	16
Carbon.....	C	12	Phosphorus.....	P	31
Chlorine.....	Cl	35.5	Potassium.....	K	39
Fluorine.....	F	19	Silicon.....	Si	28
Hydrogen.....	H	1	Sodium.....	Na	23
Iodine.....	I	127	Strontium.....	Sr	88
Iron.....	Fe	56	Sulphur.....	S	32
Lead.....	Pb	207	Tin.....	Sn	119
Lithium.....	Li	7	Zinc.....	Zn	65

TABLE 2.—Weight of 1 liter of certain gases at 0° C. and 760 mm.^a

Substance.	Formula.	Weight.	Substance.	Formula.	Weight.
		<i>Grams.</i>			<i>Grams.</i>
Carbon dioxide.....	CO ₂	1.965	Methane.....	CH ₄	0.7150
Oxygen.....	O ₂	1.429	Hydrogen sulphide.....	H ₂ S	1.522
Nitrogen.....	N ₂	1.254	Ammonia.....	NH ₃	.7615
Carbon monoxide.....	CO	1.251	Nitric oxide.....	NO	1.3417
Hydrogen.....	H ₂	.0895			

^a Hempel, Walther, Methods of gas analysis. English translation by L. M. Dennis, 1910.

TABLE 3.—Heats of hydration of some common crystalline salts.

Substance.	Reaction.	Formula.	Calories.	Authority.
Zinc sulphate.....	$\text{ZnSO}_4 + 7\text{H}_2\text{O}$	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	22,690	Thomsen.
Magnesium sulphate.....	$\text{MgSO}_4 + 7\text{H}_2\text{O}$	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	24,080	Do.
Sodium sulphate.....	$\text{Na}_2\text{SO}_4 + 10\text{H}_2\text{O}$	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	19,320	Do.
Sodium carbonate.....	$\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	21,800	Do.
Ammonium oxalate.....	$(\text{NH}_4)_2\text{C}_2\text{O}_4 + \text{H}_2\text{O}$	$(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$	3,500	Berthelot.
Aluminum sulphate.....	$\text{Al}_2(\text{SO}_4)_3 + 18\text{H}_2\text{O}$	$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$		
Potassium alum.....	$\text{K}_2\text{Al}_2(\text{SO}_4)_4 + 24\text{H}_2\text{O}$	$\text{K}_2\text{Al}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$		

TABLE 4.—Molecular heats of gases, at constant volume, concerned in the thermochemical calculations of explosives.

Substance.	Formula.	Specific heat of gas.	Substance.	Formula.	Specific heat of gas.
Carbon dioxide ^a	CO_2	6.26+0.0037 <i>t</i>	Hydrogen ^a	H_2	4.80+0.0006 <i>t</i>
Sulphur dioxide ^a	SO_2	6.26+ .0037 <i>t</i>	Methane.....	CH_4	7.10+ .0005 <i>t</i>
Water vapor ^a	H_2O	5.61+ .0033 <i>t</i>	Ammonia.....	NH_3	6.70+ .0005 <i>t</i>
Nitrogen ^a	N_2	4.80+ .0006 <i>t</i>	Hydrogen sulphide.....	H_2S	6.30+ .0005 <i>t</i>
Carbon monoxide ^a	CO	4.80+ .0006 <i>t</i>	Nitric oxide.....	NO	4.80+ .0006 <i>t</i>
Oxygen ^a	O_2	4.80+ .0006 <i>t</i>			

^a Mallard and LeChatelier, Compt. Rendus, vol. 93, 1881, p. 1014.

TABLE 5.—Specific heats of solids found in explosion reactions.

Substance.	Formula.	Temperature.	Specific heat.	Authority.
		° C.		
Aluminum oxide.....	Al_2O_3	0–100	0.1827	Nilson.
Ammonium chloride (crystallized).....	NH_4Cl	15– 45	.373	Kopp.
Barium carbonate.....	BaCO_3	11– 99	.110	Regnault.
Barium chloride (fused).....	BaCl_2	16– 47	.090	Kopp.
Calcium carbonate (marble).....	CaCO_3	0	.2028	Webber.
Carbon.....	C		.533	(<i>a</i>)
Chromic oxide.....	Cr_2O_3	21– 52	.177	Kopp.
Dolomite.....	$\text{CaMg}(\text{CO}_3)_2$	18– 47	.206	Do.
Magnesium carbonate.....	MgCO_3		.206	(<i>b</i>)
Magnetite.....	Fe_3O_4	24– 99	.1678	Regnault.
Magnesium sulphate.....	MgSO_4	25–100	.225	Pape.
Potassium bicarbonate.....	KHCO_3		.206	(<i>c</i>)
Potassium bisulphate (crystallized).....	KHSO_4	19– 51	.244	Kopp.
Potassium carbonate (fused).....	K_2CO_3	17– 47	.206	Do.
Potassium chloride (fused).....	KCl	13– 47	.171	Do.
Potassium sulphate (crystallized).....	K_2SO_4	13– 45	.196	Do.
Potassium sulphate (fused).....	K_2SO_4	15– 98	.190	Regnault.
Potassium sulphide.....	K_2S		.1615	Berthelot.
Pyrolusite.....	MnO_2	17– 48	.159	Kopp.
Quartz.....	SiO_2	20– 50	.186	Do.
Sodium bicarbonate (fused).....	NaHCO_3		.246	(<i>d</i>)
Sodium carbonate (fused).....	Na_2CO_3	18– 48	.246	Kopp.
Sodium chloride (fused).....	NaCl	13– 46	.213	Do.
Sodium sulphate (crystallized).....	Na_2SO_4	28– 57	.2293	Schüller.
Sodium sulphate (fused).....	Na_2SO_4	17– 98	.2312	Regnault.
Sodium sulphide.....	Na_2S		.2436	Gody.
Zinc oxide (ignited).....	ZnO	17– 98	.1248	Regnault.
Zinc sulphate.....	ZnSO_4	22–100	.174	Pape.

^a Assumed to be $\frac{6.4}{12}=0.533$.^b Assumed to have the same value as dolomite.^c Assumed to have the same value as potassium carbonate.^d Assumed to have the same value as sodium carbonate.

TABLE 6.—Heats of formation of some substances occurring in explosion reactions.

[The components and products are considered in their actual condition at 15° C. Carbon is considered as crystallized.]

Substance.	Components.	Products.	Heat of formation.	Authority.
			<i>Calories.</i>	
Aluminum sulphate.....	$\text{Al}_2 + \text{S}_8 + \text{O}_{12} + \text{Aq.}$	$\text{Al}_2(\text{SO}_4)_3 + \text{Aq.}$	879,700	Berthelot.
Ammonia.....	$\text{N} + \text{H}_3$	NH_3	11,900	Thomsen.
Ammonium chloride.....	$\text{N} + \text{H}_4 + \text{Cl}$	NH_4Cl	75,800	Do.
Ammonium nitrate.....	$\text{N}_2 + \text{H}_4 + \text{O}_3$	NH_4NO_3	88,050	Do.
Ammonium oxalate.....	$\text{N}_2 + \text{H}_8 + \text{C}_2 + \text{O}_4$	$(\text{NH}_4)_2\text{C}_2\text{O}_4$	270,100	Berthelot.
Ammonium sulphate.....	$\text{N}_2 + \text{H}_8 + \text{S} + \text{O}_4$	$(\text{NH}_4)_2\text{SO}_4$	281,900	Thomsen.
Barium carbonate.....	$\text{Ba} + \text{C} + \text{O}_3$	$\text{BaCO}_3(\text{amorphous})$...	285,600	Do.
Barium chloride.....	$\text{Ba} + \text{Cl}_2$	BaCl_2	197,100	Berthelot.
Barium nitrate.....	$\text{Ba} + \text{N}_2 + \text{O}_5$	$\text{Ba}(\text{NO}_3)_2$	228,400	Thomsen.
Calcium carbonate.....	$\text{Ca} + \text{C} + \text{O}_3$	CaCO_3	270,400	Do.
Carbon dioxide.....	$\text{C} + \text{O}_2$	CO_2	94,300	Berthelot.
Carbon monoxide.....	$\text{C} + \text{O}$	CO	26,100	Do.
Cellulose.....	$\text{C}_6 + \text{H}_{10} + \text{O}_5$	$\text{C}_6\text{H}_{10}\text{O}_5$	230,400	Do.
Dinitronaphthalene.....	$\text{C}_{10} + \text{H}_6 + \text{N}_2 + \text{O}_4$	$\text{C}_{10}\text{H}_6(\text{NO}_2)_2$	-4,800	Calculated.
Ferric oxide.....	$\text{Fe}_2 + \text{O}_3$	$\text{Fe}_2\text{O}_3 \begin{cases} 400^\circ \text{C.} \\ 1,000^\circ \text{C.} \end{cases}$	195,600 194,400	LeChatelier.
Hydrogen sulphide.....	$\text{H}_2 + \text{S}$	H_2S	2,700	Thomsen.
Magnesium carbonate.....	$\text{Mg} + \text{C} + \text{O}_3$	$\text{MgCO}_3(\text{pptd.})$	266,600	Berthelot.
Magnesium sulphate.....	$\text{Mg} + \text{S} + \text{O}_4$	MgSO_4	302,300	Thomsen.
Manganese dioxide.....	$\text{Mn} + \text{O}_2$	MnO_2	126,100	LeChatelier.
Methane.....	$\text{C} + \text{H}_4$	CH_4	18,900	Berthelot.
Nitric oxide.....	$\text{N} + \text{O}$	NO	-21,600	Thomsen.
Nitrobenzene.....	$\text{C}_6 + \text{H}_5 + \text{N} + \text{O}_2$	$\text{C}_6\text{H}_5\text{NO}_2$	-4,100	Berthelot.
Nitroglycerin.....	$\text{C}_3 + \text{H}_5 + \text{N}_3 + \text{O}_9$	$\text{C}_3\text{H}_5(\text{NO}_3)_3$	98,900	Do.
Nitronaphthalene.....	$\text{C}_{10} + \text{H}_7 + \text{N} + \text{O}_2$	$\text{C}_{10}\text{H}_7\text{NO}_2$	-13,800	Calculated.
Nitrotoluene.....	$\text{C}_7 + \text{H}_7 + \text{N} + \text{O}_2$	$\text{C}_7\text{H}_7\text{NO}_2$	11,300	Do.
Paraffin.....	$\text{C}_{24} + \text{H}_{50}$	$\text{C}_{24}\text{H}_{50}$	^a 270,200	Do.
Potassium bicarbonate.....	$\text{K} + \text{H} + \text{C} + \text{O}_3$	KHCO_3	233,300	Berthelot.
Potassium bisulphate.....	$\text{K} + \text{H} + \text{S} + \text{O}_4$	KHSO_4	277,100	Thomsen.
Potassium carbonate.....	$\text{K}_2 + \text{C} + \text{O}_3$	K_2CO_3	281,100	Do.
Potassium chlorate.....	$\text{K} + \text{Cl} + \text{O}_3$	KClO_3	95,800	Do.
Potassium chloride.....	$\text{K} + \text{Cl}$	KCl	105,600	Do.
Potassium bichromate.....	$\text{K}_2 + \text{Cr}_2 + \text{O}_7$	$\text{K}_2\text{Cr}_2\text{O}_7$	15,000	Berthelot.
Potassium nitrate.....	$\text{K} + \text{N} + \text{O}_3$	KNO_3	119,500	Thomsen.
Potassium perchlorate.....	$\text{K} + \text{Cl} + \text{O}_4$	KClO_4	112,500	Berthelot.
Potassium permanganate.....	$\text{K} + \text{Mn} + \text{O}_4$	KMnO_4	194,800	Thomsen.
Potassium sulphate.....	$\text{K}_2 + \text{S} + \text{O}_4$	K_2SO_4	344,600	Do.
Potassium sulphide.....	$\text{K}_2 + \text{S}$	K_2S	103,500	Sabatier.
Sodium bicarbonate.....	$\text{Na} + \text{H} + \text{CO}_3$	NaHCO_3	229,300	Thomsen.
Sodium carbonate.....	$\text{Na}_2 + \text{C} + \text{O}_3$	Na_2CO_3	272,600	Do.
Sodium chlorate.....	$\text{Na} + \text{Cl} + \text{O}_3$	NaClO_3	86,700	Do.
Sodium chloride.....	$\text{Na} + \text{Cl}$	NaCl	97,700	Do.
Sodium nitrate.....	$\text{Na} + \text{N} + \text{O}_3$	NaNO_3	111,250	Do.
Sodium perchlorate.....	$\text{Na} + \text{Cl} + \text{O}_4$	NaClO_4	100,300	Berthelot.
Sodium sulphate.....	$\text{Na}_2 + \text{S} + \text{O}_4$	Na_2SO_4	328,600	Thomsen.
Sodium sulphide.....	$\text{Na}_2 + \text{S}$	Na_2S	88,200	Sabatier.
Starch.....	$\text{C}_6\text{H}_{10} + \text{O}_5$	$\text{C}_6\text{H}_{10}\text{O}_5$	225,900	Berthelot.
Sulphur dioxide.....	$\text{S} + \text{O}_2$	SO_2	71,100	Thomsen.
Trinitronaphthalene.....	$\text{C}_{10} + \text{H}_5 + \text{N}_3 + \text{O}_6$	$\text{C}_{10}\text{H}_5(\text{NO}_2)_3$	4,200	Calculated.
Water.....	$\text{H}_2 + \text{O}$	$\text{H}_2\text{O}(\text{gaseous})$	58,100	Berthelot.
Do.....	$\text{H}_2 + \text{O}$	$\text{H}_2\text{O}(\text{liquid})$	69,000	Do.
Wood pulp.....	$\text{C}_{15} + \text{H}_{22} + \text{O}_{10}$	$\text{C}_{15}\text{H}_{22}\text{O}_{10}$	^a 463,360	Calculated.
Zinc oxide.....	$\text{Zn} + \text{O}$	ZnO	85,000	Thomsen.

^a Calculated from heat of combustion.

CHAPTER III.

CHARACTERISTICS OF THE NATURAL GAS USED AT PITTSBURGH.

By GEORGE A. BURRELL.

INTRODUCTION.

In planning the work at the Pittsburgh station it was decided to use the natural-gas supply of the city for forming the mixtures of gas and air used in the testing galleries. In order to ascertain the composition of this gas, and the extent to which the composition was liable to vary, the gas was analyzed every day for about two weeks. At the end of this period the results obtained had established the fact that the composition of the gas varied but little from week to week, and thereafter analyses were made weekly.

METHODS OF ANALYSIS.

Tests for carbon dioxide, oxygen, hydrogen sulphide, olefin hydrocarbons, and carbon monoxide were occasionally made, using large amounts of the gas, but the analyses given were made by a eudiometric method, which followed in general the scheme of Hempel.^a Since the completion of the analyses referred to in this bulletin apparatus has been devised that is superior in some respects to the Hempel apparatus for the analysis of natural gas. This apparatus will be described in a forthcoming publication of the Bureau of Mines. The burette used was graduated in tenths of 1 cubic centimeter. It was water-jacketed, and had a compensating device.^b Because of the latter, small differences in room temperature during the progress of analyses could be disregarded. This device also afforded a quite precise means of making adjustments before the taking of burette readings. Mercury was used in the measuring burette and in the combustion pipette. With the apparatus used an accuracy greater than 0.1 per cent could hardly be attained; consequently when a constituent was reported absent assumption was made that its presence could not be detected in amount greater than this figure.

^a Hempel, Walther, *Methods of gas analysis*. English translation by L. M. Dennis, 1910.

^b *Idem*, p. 61.

Discovery was early made that the accurate determination of the constituents present in the natural gas offered difficulties of no small moment. Those constituents absorbable by solutions were either absent or present in such small quantities that their estimation by ordinary eudiometric methods required strict attention to detail in handling the apparatus, and the large amount of combustible gas present required for its determination the use of a large percentage of the residual gas left after the absorption solutions had been used. Experience showed that through poor manipulation and misuse of the solutions one might easily report several tenths of 1 per cent or more of a gas that was either present in much smaller amounts than this or which was entirely absent.

CARBON DIOXIDE.

Carbon dioxide is found almost everywhere and its presence in natural gas should cause no surprise, yet the natural gas used at Pittsburgh contains only small quantities of it, usually such amounts that its presence can not be detected with the apparatus used. Passing the gas through lime water, however, shows that carbon dioxide is present.

OXYGEN.

Tests with alkaline pyrogallate solution showed the occasional presence of traces of oxygen in the samples analyzed. This oxygen was not necessarily present in the gas at the wells, but was probably introduced into the gas as it traversed the pipe lines. The quantities occasionally found were so small, however, as to lie within the accuracy of making the determinations.

OLEFIN HYDROCARBONS.

Search was made for olefin hydrocarbons by means of fuming sulphuric acid and a saturated solution of bromine water. The practice was to pass the gas into the acid and immediately withdraw it. The acid fumes were then removed by washing the gas with a solution of caustic potash. On some samples several tenths of 1 per cent reduction in volume of the sample followed. Bromine was tried several times in those cases where the sulphuric acid gave a positive result and caused one-half as much reduction in volume of the gas as that caused by the acid. Later, qualitative tests were conducted by passing the gas through a dilute solution of palladium chloride,^a but no reduction of the salt followed. This reaction is extremely delicate. In the presence of olefin hydrocarbons, carbon monoxide, or hydrogen sulphide, palladium is precipitated and appears as a

^a Phillips, F. C., Researches upon the phenomena of oxidation and chemical properties of gas. *Am. Chem. Jour.*, vol. 16, No. 4, p. 267.

dark cast or as suspended particles throughout the liquid. An examination of certain natural gases from southern California that were heavily impregnated with higher members of the paraffin series, showed that the solution of these higher paraffins in fuming sulphuric acid is very marked, and that tests for paraffin hydrocarbons in natural gas by the use of fuming sulphuric acid may be misleading. R. A. Worstell^a has also made the latter observation.

CARBON MONOXIDE.

A solution of cuprous chloride did not prove satisfactory in testing natural gas containing higher members of the paraffin series for carbon monoxide, because it exerted a slight solvent action upon those members; consequently qualitative tests were made by using dilute solutions of blood or palladium chloride. Spectroscopic examinations also were made, but carbon monoxide was in no case detected. Experimental work on known amounts of carbon monoxide showed that the presence of 0.1 per cent of carbon monoxide could be detected by the means employed. The method consisted in passing 200 cubic centimeters of the natural gas at the rate of 10 cubic centimeters per minute through a dilute blood solution (in which 1 volume of blood was diluted 225 times with water) in test tubes 6 inches long and 0.75 inch wide. The pink color characteristic of carbon monoxide-haemoglobin was not imparted to the blood solution.

HYDROGEN SULPHIDE.

Tests for hydrogen sulphide were made by means of iodine and starch, also by passing the gas through a solution of lead acetate for several hours. No hydrogen sulphide was found.

HYDROGEN.

Palladium asbestos heated to 100° C. was used in testing for hydrogen. A contraction in volume was never obtained by passing the gas over this substance. The working qualities of the palladium asbestos were checked by means of gas mixtures containing known quantities of hydrogen.

PARAFFIN HYDROCARBONS.

The slow-combustion method was used for the determination of the paraffin hydrocarbons, as follows: Fifty cubic centimeters of the gas residue were introduced into a Dennis-Winkler slow-combustion pipette and the platinum spiral was heated to a bright red; 150 cubic centimeters of oxygen were then added at the rate of 10 to 15 cubic centimeters per minute. By this procedure the gas burned quietly

^a Jour. Am. Chem. Soc., vol. 21, 1899, p. 245, and vol. 20, 1898, p. 264.

as fast as it entered the pipette and an explosion consequent on an accumulation of gas and air was prevented. An air blast was used to expedite the cooling of the pipette after combustion; it proved efficient as it reduced the time required for combustion and cooling to about six minutes. An analysis of natural gas follows which shows the method of procedure and calculation.

Analysis of natural gas.

	Burette reading.	Per cent.		Burette reading.	Per cent.
	<i>Cubic centi-meters.</i>			<i>Cubic centi-meters.</i>	
Volume of sample taken.....	100.0		Volume after carbon dioxide		
Carbon dioxide.....	99.9	0.1	absorption.....	40.1	
Oxygen.....	99.9	.0	Carbon dioxide.....	57.4	
Paraffins by combustion—			Partial methane.....	41.0	
Total residue.....	99.9		Partial ethane.....	8.2	
Portion taken.....	50.0		Total methane.....		82.0
Oxygen added.....	150.0		Total ethane.....		16.4
Total volume.....	200.0		Nitrogen.....		1.5
Volume after burning.....	97.5				
Contraction.....	102.5				100.0

The paraffin hydrocarbons have the general formula C_nH_{2n+2} . The following list includes six of these hydrocarbons:

CH_4	Methane.
C_2H_6	Ethane.
C_3H_8	Propane.
C_4H_{10}	Butane.
C_5H_{12}	Pentane.
C_6H_{14}	Hexane.

The first four members are gases at ordinary temperatures.

Hexane is the main constituent of the gasoline obtained from the distillation of oils having paraffin bases. Gasoline obtained from natural gas in the oil fields contains lower members of the paraffin series than gasoline procured by refining petroleum. So volatile is some of the gasoline from natural gas that difficulty has been experienced in preventing considerable loss of the liquid by evaporation. Liquid butane has a boiling point of $1^\circ C$,^a consequently a rapid volatilization takes place at ordinary temperatures from natural-gas gasoline containing butane.

It is believed that paraffins higher than ethane exist in traces only in the natural gas used at Pittsburgh. Because of the high rock pressure to which the gas is subjected in the earth, and the miles of pipe line traversed by some of the gas before it reaches Pittsburgh, paraffins higher than ethane are probably present in very small quantities in the gas as it enters the city. Because of the lack of a sufficient proportion of the higher paraffins, the manufacture of gasoline from the gas at Pittsburgh is not a commercial success.

^a Watt's Dictionary of Chemistry, 1905, vol. 1, p. 638.

A test conducted by passing the gas very slowly for five hours through a glass tube 8 inches long and 0.5 inch wide, placed in a freezing mixture having a temperature of -10°C ., resulted in no visible condensation. This test does not show the entire absence of butane, but some condensation should have occurred were the gas present in quantity beyond that required to saturate the other gases with butane vapor at the temperature used. Propane in the liquid condition boils at -17°C .^a

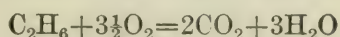
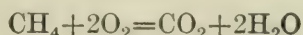
The solubility of natural gas in absolute alcohol was tried by shaking 1 cubic centimeter of the latter with 100 cubic centimeters of natural gas in a Hempel explosion pipette over mercury. The alcohol dissolved 2.5 cubic centimeters of the gas.

The solubility of some of the paraffin hydrocarbons in alcohol is as follows:

1 volume of alcohol dissolves	0.523	volume of methane at 0°C . ^b
1 volume of alcohol dissolves	1.5	volumes of ethane. ^c
1 volume of alcohol dissolves	6.0	volumes of propane. ^d
1 volume of alcohol dissolves	18.0	volumes of butane. ^e

The relative solubilities of the individual paraffins as compared to the solubility of the natural gas in the alcohol indicates that the higher paraffins are not present in the latter mixture in large amounts.

No satisfactory method of calculating the members of the paraffin series in an unknown mixture of two or more of the latter is known. No absorbents are known that will qualitatively absorb in turn the different members and leave the others untouched. Consequently they are determined as a whole by combustion as stated before. In the typical example given, the combustion data, that is, the carbon dioxide formed and the contraction produced by the complete combustion of the natural gas, have been calculated to methane and ethane according to the following reactions:



Let x =the quantity of methane, and let y =the quantity of ethane.

Then the carbon dioxide produced $=x+2y$, and the contraction produced $=2x+2\frac{1}{2}y$.

The amounts of methane and ethane as determined by this procedure are not correct if a mixture of more than two paraffins is present, but the figure for total paraffins determined by this calculation is correct, regardless of the quantity or character of the individual

^a Watt's Dictionary of Chemistry, 1907, vol. 4, p. 307.

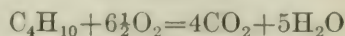
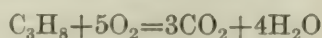
^b Watt's Dictionary of Chemistry, 1906, vol. 3, p. 251.

^c Watt's Dictionary of Chemistry, 1906, vol. 2, p. 460.

^d Watt's Dictionary of Chemistry, 1907, vol. 4, p. 307.

^e Watt's Dictionary of Chemistry, 1905, vol. 1, p. 638.

paraffins present. This can be shown as follows: Propane and butane combine with oxygen according to the following reactions:



Let an assumption be made of a mixture of 100 volumes of paraffins divided as follows:

	Volumes.
CH_4	80
C_2H_6	15
C_3H_8	4
C_4H_{10}	1

This mixture with sufficient oxygen for complete combustion would produce 126 volumes of carbon dioxide and undergo a contraction in volume of 213 volumes. The combustion data if calculated as methane and ethane are equivalent to 74 volumes of methane and 26 volumes of ethane. The proportions are incorrect, but the amount of total paraffins is exact. The 74 volumes of methane and 26 volumes of ethane consume the same amount of oxygen upon burning as the 100 volumes of the mixture. In view of these facts it can be seen that the heating value of the natural gas used at Pittsburgh calculated on the assumption that methane and ethane only are present is correct. Let the following heating values be used:

Methane has a heating power of 1,065 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury.

Ethane has a heating power of 1,861 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury.^a

According to the analysis on page 66, the natural gas has a heating value of 1,179 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury. This figure has been verified by trial with a Junker calorimeter.

COLLECTION AND ANALYSIS OF GAS SAMPLES FROM THE TESTING GALLERY.

For a long time a value, called the methane equivalent, was determined daily. It is now determined biweekly. The methane equivalent is the volume of carbon dioxide that 100 cubic centimeters of the gas will produce on undergoing complete combustion and is equal to the carbon dioxide produced by the combustion of the methane and ethane.

Samples of the various mixtures of gas and air, collected over water in a suitable container by the engineer in charge of the gallery, were sent to the laboratory for analysis. Upon arrival at the laboratory a sample was transferred to a water-jacketed burette, measured, and

^a Landolt-Bornstein, *Physikalisch-chemische Tabellen*, fifth edition, p. 425; from J. Thomsen, *Thermochemische Untersuchungen*, vol. 4, 1886.

passed into the slow-combustion pipette. If the sample was an explosive mixture, enough air was added to make the mixture nonexplosive. After combustion the gas was drawn back into the burette, measured, and transferred to the pipette containing potassium hydroxide. The volume of carbon dioxide found was then divided by the methane equivalent and the result multiplied by 100 to obtain the percentage of natural gas in the sample. This figure was then multiplied by the percentage of the various constituents of the natural gas as determined by the analysis for that week, giving the percentages of methane, ethane, and nitrogen in the gas mixture.

At present in analyzing gas-air mixtures the contraction due to combustion only is determined. This figure is divided by the figure giving the contraction in centimeters produced by complete oxidation of 100 cubic centimeters of natural gas, to determine the amount of natural gas in the gas-air mixture. The calculation is continued as stated above.

To show that the method of collecting samples of the gas-air mixtures over water had no effect on the accuracy of the work, the two following sets of analyses are cited. The first set was made immediately upon taking the sample and the second set after the sample had stood over water for two days.

Analyses of gas-air mixtures.

Date analyzed.	Natural gas.		
	Sample 1.	Sample 2.	Sample 3.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Sept. 9, 1909.....	4.15	4.29	4.29
Sept. 11, 1909.....	4.10	4.27	4.27

Collecting samples over water was permissible because there were in the gas no constituents upon which water has an appreciable solvent action.

EXPLOSIBILITY OF GAS-AIR MIXTURES.

In order to interpret satisfactorily the results of the tests of explosives at the Pittsburgh station, the explosive characteristics of the gas-air mixtures used were investigated. Mixtures of combustible gases with air are explosive within certain definite limits. If, starting with the most explosive mixture, the proportion of air in the mixtures be gradually increased, the explosions become less and less violent until at last a mixture is obtained containing so small a percentage of gas that it can not be exploded. This is called the lower limit of explosion. Similarly, if the proportion of gas be gradually increased a mixture is finally obtained that is incapable of explosion. This is called the upper limit of explosion.

These limits for different gases appear to be determined largely by the quantity of air required for complete combustion. The explosion limits of the same mixture will vary somewhat with the size and shape of the vessel used, the method of ignition employed, and the temperature and pressure of the mixture. Hence it is practically impossible to define exact limits within which gas-air mixtures are explosive. If a spherical vessel be used, the limits are somewhat wider than those obtained by the use of a long, narrow one; also, if the mixture be ignited by a flame, especially if the flame be applied at the bottom of the vessel, the limits differ from those obtained when the mixture is ignited by an electric spark. The size of the spark also makes some difference.

The explosion limits^a of the more common combustible gases, such as methane, hydrogen, and carbon monoxide, have been carefully investigated and values that agree fairly well have been determined by different chemists.

The higher homologues of the paraffin series, when in the gaseous state, have narrower explosion limits than the lower members. Methane, for instance, has a lower limit of 6 per cent gas and a higher limit of 13 per cent, while pentane (fifth in the series) has a lower limit of 2.4 per cent and a higher limit of 4.9 per cent. Because natural gas contains ethane one would expect its explosion limits to be somewhat narrower than those of methane. Experiments made at different times during the year showed that the limits for natural gas varied somewhat, even though the conditions under which the experiments were performed were nearly similar. The following results, obtained by using a Hempel explosion pipette, with mercury as the confining fluid, show this variation:

Explosion limits of mixtures of air and natural gas.

	Percentage of gas.	
	Low limit.	High limit.
Sample No. 1.....	4.8	.....
Sample No. 2.....	5.0	12.4
Sample No. 3.....	5.3	11.8

As the gas did not change enough in composition to account for this variation, conditions in the experiments by which the limits were determined were probably responsible. In the case of the third sample, water instead of mercury was used in the burette in which the gas and air were measured, and the spark was more feeble than in the first and second cases. In addition, the values were determined under different weather conditions.

^aIn this discussion of the explosion limits of a gas, the gas is assumed to be mixed with air unless a contrary statement is made.

COMPARISON OF EXPLOSION LIMITS OF VARIOUS GAS-AIR MIXTURES.

In determining the explosion limits of natural gas and air mixtures, the main essential has to do with a comparison with the explosion limits of other gases, principally with those of methane and, to a lesser degree, with those of coal gas. The last comparison is of consequence, because coal gas is used at the Woolwich testing gallery in England. Consequently the explosion limits for natural gas, methane, and coal gas were determined on the same day, with the same apparatus, and under conditions that were kept as nearly constant as possible. In common with the results obtained by other investigators, the lower limit of explosibility of gaseous mixtures was found to be somewhat below the limit at which the gas undergoes complete combustion. A mixture of natural gas and air can be exploded when it contains 5 per cent of gas, but complete combustion ensues only when the proportion of gas reaches to 5.4 per cent. For comparison the results obtained by other investigators are given below with those obtained at the Pittsburgh laboratory of the Bureau of Mines. The lowest point at which complete combustion was obtained was determined by measuring the carbon dioxide produced. It was found that in all cases the lower limit of explosibility coincided with the flash as seen by the eye. Where no flash could be seen, a measurable contraction in volume did not take place.

Explosion limits of gases.

Gas.	Remarks.	Low limit.	High limit.	Authority.
Natural gas used at Pittsburgh.	Incomplete combustion.....	5.0	} 12.0	Burrell.
Do.....	Complete combustion.....	5.4		
Methane.....	Incomplete combustion.....	5.3	} 12.8	Do.
Do.....	Complete combustion.....	5.7		
Do.....	do.....	6.1	12.8	Eitner. ^a
Do.....	Fired from below.....	5.0	13.0	Clowes. ^b
Do.....	Fired from above.....	6.0	11.0	Do.
Do.....	do.....	6.0	13.0	Roszkowski. ^c
Coal gas.....	Incomplete combustion.....	6.3	} 19.1	Burrell.
Do.....	Complete combustion.....	7.9		
Do.....	do.....	7.9	19.1	Eitner. ^a
Do.....	Fired from below.....	6.0	29.0	Clowes. ^b
Do.....	Fired from above.....	9.0	22.0	Do.
Do.....	do.....	7.0	22.6	Roszkowski. ^c
Ethylene.....	do.....	4.0	22.0	Clowes. ^b
Pentane.....	Complete combustion.....	2.4	4.9	Eitner. ^a
Hydrogen.....	do.....	9.45	66.4	Do.
Carbon monoxide.....	Fired from below.....	5.0	72.0	Clowes. ^b
Do.....	Complete combustion.....	16.5	74.95	Eitner. ^a
Do.....	Fired from below.....	13.0	75.0	Clowes. ^b
Acetylene.....	do.....	14.3	74.6	Roszkowski. ^c
Do.....	do.....	3.0	82.0	Clowes. ^b

^aEitner P., Jour. Gasbel, vol. 45, pp. 21-24, 69-72, 90-93, 112-115. Abstract in Jour. Soc. Chem. Ind., vol. 21, 1902, p. 395.

^bClowes and Redwood, Detection and estimation of inflammable gases and vapor in air, 1896, pp. 2 and 6.

^cKubierschky, K., Zeitschr. angew. Chem. 1901, vol. 6, pp. 129-132. Abstract in Jour. Soc. Chem. Ind., vol. 20, 1901, p. 345.

The experiments mentioned by Eitner were made over water in a Bunte explosion burette having a capacity of 110 cubic centimeters and an internal diameter of 19 millimeters. The ignitions were brought about by the spark of a powerful induction coil. Only those

combustions in which a contraction corresponding to the complete combustion of the gas was observed were accepted as explosions. The lower limits given by Eitner were determined when an open cylinder 62 millimeters in internal diameter was used, ignition being effected by applying the flame at the top of the vessel. They were as follows:

	Per cent.
Hydrogen.....	8.5
Ethylene.....	3.4
Methane.....	6.3
Pentane.....	1.3

Clowes's experiments were made in a glass cylinder 3 inches in internal diameter and closed at one end. Ignition was effected by firing the gas with a flame, both from above and below.

The coal gas mentioned in the above table of the explosion limits of gases had the following composition:

Composition of coal gas used in experiments.

Constituent gases.	Gas used by Eitner.	Gas used by Burrell.
	<i>Per cent.</i>	<i>Per cent.</i>
Hydrogen.....	50.75	43.0
Methane.....	34.30	36.5
Carbon monoxide.....	7.05	10.0
Illuminants.....	4.25	6.4
Carbon dioxide.....	1.95	1.6
Nitrogen.....	1.70	2.5

It was noted that the dividing line between an air and coal-gas mixture that would not and one that did explode (at the lower limit) was not sharply defined. With 6.3 per cent of gas a reduction in volume of 0.3 cubic centimeters was recorded. From this point the explosion gradually increased in violence until the proportion of gas was 7.9 per cent, when complete combustion took place. The most violently explosive mixture of coal gas and air contains considerably more gas than 7.9 per cent. On the other hand, natural gas and methane behaved differently; there was a sharp dividing line (at the lower limit) between a mixture that would not explode and one that would. Thus with 4.9 per cent of gas no ignition took place, whereas with 5 per cent of gas there was a pronounced explosion.

EFFECT OF CARBON DIOXIDE ON EXPLOSION LIMITS.

As a result of recent experiments, J. K. Clement, physicist of this bureau, finds that the presence of carbon dioxide in mixtures of methane and air, or of the natural gas used at Pittsburgh and air, reduces the explosibility of the mixture to a much greater extent than the presence of nitrogen, and attributes this effect to the high specific heat of carbon dioxide. Under the conditions of his experiments the mixture of natural gas and air, with no carbon dioxide, was found

to have explosive limits lying between 5.5 per cent, low limit, and 11.6 per cent, high limit. He found that natural gas when mixed with air containing 2.5 per cent of carbon dioxide had explosive limits lying between 5.7 per cent, low limit, and 10.5 per cent, high limit. The mixture of air and carbon dioxide with which the natural gas was mixed had the following composition:

	Per cent.
CO ₂	2.5
O ₂	20.6
N ₂	76.9
	100.0

When the gas was mixed with air in which 5 per cent of the air had been replaced by carbon dioxide the explosive limits were between 6.2 per cent, low limit, and 9.7 per cent, high limit. In this case the mixture of air and carbon dioxide with which the natural gas was mixed had the following composition:

	Per cent.
CO ₂	5
O ₂	20
N ₂	75
	100

When natural gas was mixed with air in which 95 per cent of the nitrogen had been replaced by carbon dioxide, an explosion could be obtained only when 8.4 per cent of natural gas was present. When the gas was mixed with air in which 31 per cent of the nitrogen had been replaced by carbon dioxide, the explosive limits lay between 6 and 11 per cent. When natural gas was mixed with air in which 4 per cent of the oxygen of the latter had been replaced by carbon dioxide, the explosive limits lay between 5.2 and 10.5 per cent. When mixed with air in which 6.3 per cent of the oxygen was replaced by carbon dioxide, no explosion occurred. Nearly similar results were obtained when methane was used in place of the natural gas.

It will be seen that carbon dioxide exerts an influence upon an explosive mixture of natural gas or methane and air even when the proportion of oxygen is not greatly reduced. At the Frameries testing gallery in Belgium the precaution is taken of removing the carbon dioxide from the pit gas that is used at that place.

TEMPERATURE OF IGNITION.

Dixon and Howard^a obtained the following ignition temperatures when the gases under investigation were mixed with air:

	° C.
Hydrogen (about).....	585
Moist carbon monoxide.....	651
Methane.....	650-750
Ethane.....	520-630

^a Chemical News, vol. 99, 1909, p. 139.

They state that neither changing the proportions of the gas mixture nor varying the rate of flow (both between wide limits) had an appreciable effect upon the values they obtained.

Freyer and Meyer^a obtained the following values when they allowed the gas-air mixtures to flow freely through a tube:

	° C.
Methane.....	650-750
Ethane.....	606-650

While the following results were obtained when the mixtures were in a closed space:

	° C.
Methane.....	606-650
Ethane.....	530-606

These results show that the presence of ethane in the natural gas used at Pittsburgh gives the gas a slightly lower ignition temperature than methane. The ignition temperature of coal gas is given as 600° to 655° C. by various writers. C. L. Cabot^b makes the statement, on the basis of experiments conducted by himself, that the ignition temperature of the natural gas of western Pennsylvania is higher than that of coal gas.

AIR REQUIRED FOR COMPLETE COMBUSTION.

A computation based on the results of the analysis of natural gas given on page 66 shows that the largest proportion of gas that can be present in a mixture of natural gas and air, and yet undergo complete combustion, is 8.6 per cent, or, in other words, the proper ratio of gas to air to form the most explosive mixtures is 1:11.6. Mixtures of natural gas and air in this and other proportions were made, exploded over mercury in a Hempel explosion pipette, and the products of combustion examined with the following results:

Products of combustion of mixtures of natural gas and air.

	Volumes of—					
	Gas taken.	Gas and air.	CO ₂ produced.	CO produced.	O ₂ after combustion.	Gas found corresponding to CO ₂ produced.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Sample No. 1.....	8.5	100.0	9.6	.....	0.3	8.3
Sample No. 2.....	8.6	100.0	9.7	.....	.4	8.4
Sample No. 3.....	8.6	100.0	9.7	.....	.4	8.4
Sample No. 4.....	8.6	100.0	9.8	.....	.1	8.5
Sample No. 5.....	8.7	100.0	9.7	.....	.3	8.4
Sample No. 6.....	8.8	100.0	9.3	.....	.3	8.1
Sample No. 7.....	8.8	100.0	9.7	.....	.1	8.4
Sample No. 8.....	8.9	100.0	9.3	.....	.3	8.1
Sample No. 9.....	9.3	100.0	8.7	0.7	.1	.....
Sample No. 10.....	9.5	100.0	8.7	1.0	.1	.....
Sample No. 11.....	11.0	100.0	6.2	5.8	.1	.....
Sample No. 12.....	11.0	100.0	6.0	6.0	.....	.....

^a Jour. Chem. Soc. (London), vol. 94, 1893, p. 257.

^b Jour. Soc. Chem. Ind., vol. 11, 1892, p. 801.

These figures reveal several interesting facts. Theoretically those mixtures containing 8.6 per cent gas should undergo complete combustion with the consumption of all the oxygen present and with the production of an equivalent quantity of carbon dioxide. In samples 1, 2, 3, and 4 the quantity of carbon dioxide obtained did not exactly correspond to complete combustion of the gas, but it will be noted that a small percentage of oxygen was detected. The carbon dioxide equivalent of this oxygen plus the quantity of carbon dioxide produced gives a result equal to the quantity of gas taken, indicating that the analyses in total paraffins of the natural gas as cited are close to the truth.

In samples 5, 6, 7, and 8 not enough oxygen was present for complete combustion of the gas, that is, the proper ratio of gas to air (1:11.6) was exceeded. Even in samples 9, 10, 11, and 12, where a considerable percentage of carbon monoxide was produced, a measurable quantity of oxygen could be detected.

The experiments are of further interest in showing the large quantity of carbon monoxide produced when an insufficient supply of oxygen was present. Undoubtedly carbon monoxide was formed in the combustion of samples 5, 6, 7, and 8, but in quantities too small for quantitative measurement by the means employed. Subsequently another mixture corresponding to sample 6 was prepared and exploded and carbon monoxide was detected by means of the blood reaction. In the analyses of samples 11 and 12, the gases left after combustion were passed through fuming sulphuric acid in order to see if any acetylene or other intermediate products of reaction were present, but none was detected.

Because of some difference of opinion regarding the products formed by the incomplete combustion of methane, experiments were performed in which mixtures of methane and air were exploded in a Hempel explosion pipette with not enough oxygen for the complete combustion of the methane, as follows:

EXPERIMENT NO. 1.

Original mixture: 9.90 volumes of CH_4 + 88.84 volumes of air = 10.03 per cent CH_4 .

Contraction due to explosion = 17.39 volumes.

Volume of products found after combustion:

	Volumes.
CO_2	8.27
CO	1.73
H_2	1.13
N_2	70.22
O_2	None.
CH_4	None.
C_2H_4	None.
C_2H_2	None.
	81.35

EXPERIMENT NO. 2.

Original mixture, 10.83 volumes of CH_4 + 88.00 volumes of air, =10.96 per cent CH_4 .
 Contraction due to explosion=15.20 volume.

Volume of products found after combustion:

	Volumes.
CO_2	6.80
CO	3.75
H_2	3.07
N_2	70.00
O_2	None.
CH_4	None.
C_2H_4	None.
C_2H_2	None.
	83.62

Inspection of the above results shows that no methane remained unburned; that all of the carbon of the methane oxidized either to carbon dioxide or to carbon monoxide, and that part of the hydrogen burned, leaving the remainder free in the residual gas.

Four references relative to the formation of carbon monoxide are used by R. T. Chamberlin.^a They are substantially as follows:

1. The French fire-damp commission says that a mixture of methane and air containing 12 per cent of methane produces 3.9 per cent of carbon monoxide upon explosion.

2. Broockman states that the explosion of fire damp produces no carbon monoxide.

3. Heise and Herbst state that the elements carbon and hydrogen as combined in methane, never become separated except when sufficient oxygen is present for the complete oxidation of the two elements.

4. Beard, quoting Thomas, states that carbon monoxide forms as the result of the explosion of fire damp when the proportion of methane is increased above that in the most explosive mixture (9.57 per cent methane and 90.43 per cent air).

The results shown in the above table substantiate the conclusions of the French fire-damp commission and of Thomas, but contradict the findings of Heise and Herbst and of Broockman.

SENSITIVENESS OF GAS-AIR MIXTURES TO EXPLOSION.

An important factor in testing explosives for use in coal mines is the formation of that mixture of natural gas and air which is most sensitive to explosion.

H. Couriot says ^b that the most sensitive mixture of methane and air contains 9.5 per cent methane and 90.5 per cent air; in other words, the most sensitive mixture of methane and air is that in which the maximum quantity of methane undergoes complete combustion.

^a Explosive mine gases and dusts, U. S. Geol. Survey Bull. No. 383, 1909, pp. 11, 12.

^b Compt. Rend., vol. 126, 1898, pp. 750-753.

F. Emich states^a that the sensitiveness of the mixture may be determined by igniting the mixture when it is flowing slowly in a thin layer between two glass plates so arranged that the distance between them can be varied by measured amounts. Each plate has a platinum wire sealed in it, the terminal of the wire being flush with the inner side of the plate and exactly opposite the terminal in the other plate. He calls that mixture the most sensitive which requires the smallest spark for ignition. In other words, inflammability is inversely proportional to the length of the spark required for ignition. He found that inflammability is nearly proportional to pressure, and that a change in temperature had little effect on the point of ignition. In the case of a mixture of hydrogen and oxygen, an increase from ordinary atmospheric temperature to 380° C. increased the inflammability of the mixture by only one-fourth.

The most inflammable mixtures of hydrogen, methane, and carbon monoxide with oxygen that were obtained by Emich were as follows:

One volume of hydrogen and one volume of oxygen.

One volume of methane and three volumes of oxygen.

Two volumes of carbon monoxide and one volume of oxygen (moist).

A device similar to that used by Emich was tried at Pittsburgh for determining the most sensitive mixture of natural gas and air. The results showed that the most sensitive mixture contained between 8.5 and 9 per cent of gas. An 8.5 per cent mixture ignited as readily as a mixture containing 9 per cent of gas; in other words the mixture of gas and air that is most sensitive to ignition is about the same of that which is most violently explosive.

SUMMARY.

The results of this investigation may be summarized as follows:

1. The natural gas used at Pittsburgh varies so little in composition throughout the year that for the purpose to which the gas is put at the testing station the variation may be considered negligible..

2. The chemical and explosive reactions of a mixture of this natural gas and air are like those of fire damp; consequently, tests of explosives in the presence of such a mixture give a good indication of the probable result of using the explosives in the presence of fire damp.

3. A mixture of this natural gas and air appears to be better suited for use in testing explosives than mixtures of acetylene and air, and coal gas and air, or a mixture of methane and such gases as hydrogen or carbon monoxide.

^a Monatschr. für Chem., vol. 19, 1898, pp. 299-320; and vol. 21, 1900, pp. 1061-1078.

CHAPTER IV.

APPARATUS AND METHODS FOR PHYSICAL TESTS OF EXPLOSIVES.

By CLARENCE HALL.

PHYSICAL EXAMINATION.

At the Pittsburgh testing station a physical examination is made of all explosives submitted for official tests. This examination includes the determination of the average diameter, length, and weight of the cartridge, whether or not the cartridge has been redipped, the apparent specific gravity of the cartridge as determined by sand, and the color and consistency of the explosive.

The apparent specific gravity of the cartridge as determined by sand is an important item, because it enters directly into the formula for determining the maximum pressure of the explosive in its own volume (in a space equivalent to that occupied by the explosive); it is also of importance in preparing charges for tests, because the effort is made to keep the specific gravity of the explosive the same in all tests. The salient feature in the determination of apparent specific gravity by sand is the method employed to determine the volume of the cartridge. The same form of computation is necessary that is used in determining specific gravity by water, except that the weight of the sand displaced by the cartridge is divided by the density of the sand to determine the volume of the cartridge.

This method was devised to overcome two obstacles: (1) The impracticability of determining the volume of a cartridge by measurement because of irregularities in form, and (2) the impossibility of using water in determining volume because of the absorption of water by the explosive.

The color of the explosive is determined by comparison with the 48 typical colors printed in the Standard Dictionary under the word "spectrum."

In this bulletin the consistency of the explosives tested, if given, is reported according to two classifications. The older scheme gave the structure as granular, fibrous, or powdered, and the cohesiveness as very cohesive, moderately cohesive, slightly cohesive, and not cohesive. More recently, however, the classification of explosives with respect to their structure, etc., has been elaborated, and all explosives are now classified with regard to the following characteristics, as shown herewith:

1. Granulation: Structure—(a) granular, (b) fibrous, (c) powdered; size—(a) very fine, (b) fine, (c) coarse, (d) very coarse.
2. Liquidness: (a) Very wet, (b) wet, (c) dry, (d) very dry.
3. Hardness: (a) Very hard, (b) hard, (c) soft, (d) very soft.
4. Cohesiveness: (a) Very cohesive, (b) moderately cohesive, (c) slightly cohesive, (d) not cohesive.

THE BALLISTIC PENDULUM.

The ballistic pendulum, illustrated in Plate I, *B*, is used to determine the relative weights of different explosives that, when fired, will produce equal deflections of the pendulum. Obviously, the ballistic test is purely comparative, and a standard explosive with which to make comparisons must be determined upon. The standard explosive selected for this purpose is a dynamite having the following composition: Nitroglycerin, 40 per cent; sodium nitrate, 44 per cent; wood pulp, 15 per cent; calcium carbonate, 1 per cent.

The quantity of this dynamite taken to make up the standard charge is one-half pound (227 grams). It is loaded in a prescribed manner, which is described later, and is fired with a No. 6 electric detonator.

The ballistic apparatus consists of two essential parts—the cannon in which the charge is fired, and the pendulum which receives the impact of the products of explosion and of the stemming.

The quantity of stemming used is always 1 pound, except for slow-burning explosives, for which 2 pounds are used.

The cannon is identical in form, dimensions, and construction with those used in gas and dust gallery No. 1 and with that used in making the flame tests. It is fastened by straps and rods to a four-wheeled truck, which runs on a 30-inch (76.2-centimeter) gage track. Behind the truck and 9 feet from the face of the mortar that constitutes the pendulum is a backstop or bumper. The cannon is carefully placed so that the axis of its bore is in line with that of the mortar.

The pendulum consists of a 12.2-inch (30.9-centimeter) United States Army mortar, weighing 31,600 pounds (14,333 kilos), which was supplied by the Bureau of Ordnance of the War Department. The mortar rests in a stirrup made of two machine-steel rods $1\frac{1}{2}$ inches (3.8 centimeters) in diameter, each bent into a U shape. The ends of each of these rods are passed through two cast-steel saddles, which fit over a steel supporting beam. The supporting beam is 8 by 4 inches (20.3 by 10.2 centimeters) in section and 87 inches (221 centimeters) long. This beam is provided with two nickel-steel (3 per cent nickel) knife-edges, which are countersunk into its lower face near each end. (See fig. 1.) The knife-edges rest on bearing plates measuring 2 by 8 by 10 inches (5.08 by 20.3 by 25.4 centimeters)

and provided with small grooves to keep the knife edges covered with oil and protected from the weather. The bearing plates rest on base plates measuring 1 inch by 17 inches (2.54 by 43.2 centimeters) in section and 48 inches (121.9 centimeters) long, which are anchored by $\frac{5}{8}$ -inch (1.59-centimeter) bolts, 28 inches (71.1 centimeters) long, to the concrete piers between which the mortar swings.

The two concrete piers are each 51 by 120 inches (130 by 305 centimeters) at their bases, and 139 inches (353 centimeters) high. The inside walls of these piers are vertical, and the clearance between them is 60 inches (152 centimeters). The outside walls taper so that the piers are only 17 inches (43.2 centimeters) thick at the top. On one of the piers is a coupling box by means of which the electric circuit for firing the charges is completed.

The extent to which the mortar is deflected when the cannon is discharged into it is measured by an automatic recording device.

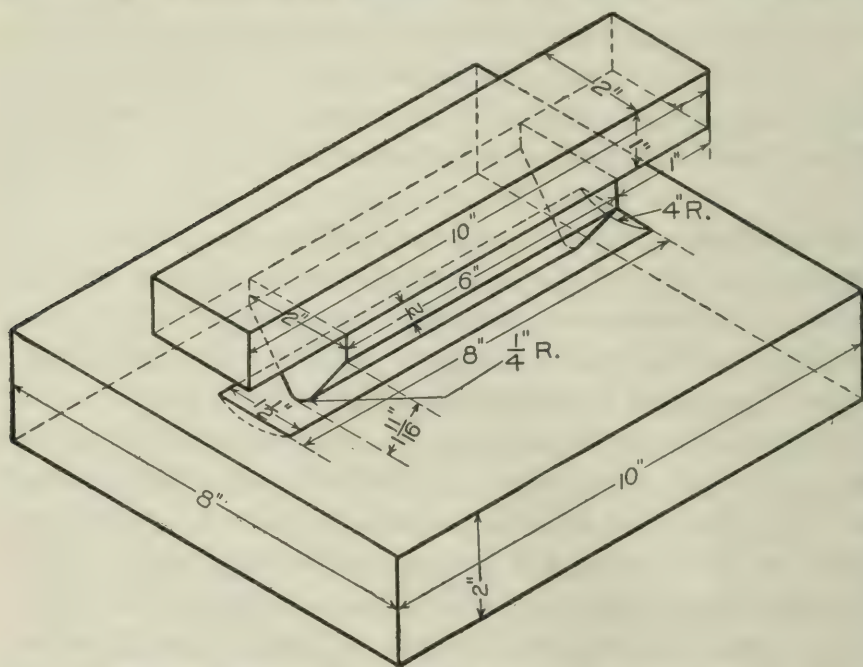


FIGURE 1.—Bearing plate and knife edge of ballistic pendulum.

This consists of a graduated scale with an index and vernier which are set on a steel base fastened to a concrete footing back of the mortar. The movable parts are actuated by a contact rod, set in guides,

which bears against a stud bolt in the bottom of the mortar directly below its center of gravity. The radius of swing of the mortar pendulum measured from the knife edges to the base of the stud bolt is $114\frac{7}{16}$ inches (291 centimeters). The radius of swing measured from the knife edges to the center of the trunnions of the mortar is $89\frac{3}{4}$ inches (228 centimeters). The scale, with its index and vernier, is detachable, and when not in use is carefully stored to protect it against the weather. The recording device measures the swing of the pendulum to within 0.01 inch (0.254 millimeter).

METHOD OF CONDUCTING TEST.

The cannon is loaded with a carefully weighed charge in which an electric detonator of the strength required by the character of the explosive has been inserted. After the charge is tamped, the



A. GAS AND DUST GALLERY NO. 1.



B. BALLISTIC PENDULUM.

cannon is rolled up within $\frac{1}{16}$ inch (1.59 millimeters) of the muzzle of the mortar. This distance is fixed by stops on the track which meet the front wheels of the truck carrying the cannon. The legs of the electric detonator or igniter are then connected to the electric firing line, and when all is secure the man in charge of the loading inserts a safety plug (which he has until then carried, and without which the charge can not be exploded) in its proper place in the coupling box, retires a safe distance to where the firing machine is located, and explodes the charge.

The loading and tamping are done with tamping sticks of uniform pattern, and care is taken to use as uniform pressure as possible. The stemming is dry clay. As already stated, 1 pound (0.45 kilo.) is used for detonating explosives and 2 pounds (0.91 kilo.) for explosives like gunpowder that require a greater degree of confinement in order that they may produce their maximum effect. The method of charging and tamping used here is followed in charging and tamping the explosives used in the other tests made at the Pittsburgh testing station, when stemming is used.

The deflection produced by exploding equal weights of the standard dynamite varies slightly, even though the charges are tamped in the cannon with the same pressure, stemmed with the same weight of fire clay, and fired by the same grade of detonator. Several factors produce this variation. One is the position of the knife edges supporting the pendulum mortar, and to eliminate as nearly as possible the variation from this source the knife edges are trammed before each trial. Other factors effecting the deflection are the direction and velocity of the wind, the condition of the bore hole in the cannon, and variations in the condition of the charge due to slight and unavoidable differences in the pressure used in loading and tamping. No one of these factors can be absolutely eliminated, but to reduce their effect to a minimum the explosive under examination is tested directly against the standard dynamite, both being handled and charged by the same person and the tests conducted on the same day and as nearly as possible under the same conditions. This procedure tends to eliminate the personal equation, through its effects becoming nearly uniform, and to minimize the variation produced by the wind, since the latter is fairly uniform during the period of test. The effect produced by variation in the condition of the bore hole is the most difficult factor to eliminate.

In detail, the procedure adopted in making a test is as follows:

Three trials of one-half pound (227 grams) charges of the standard dynamite are made and the average swing noted. Tentative trials of the explosive under test are then made until the charge gives a swing approximately that of the average swing produced by the

standard dynamite. This result is then confirmed by three trial rounds of the explosive under test. If the average swing from these three rounds is within 0.2 inch (0.5 centimeter) of the average swing produced by the standard dynamite and if the three swings do not vary more than 5 per cent, the test is accepted as satisfactory.

The "unit deflective charge" of the explosive under test, or, in other words, the weight of the explosive which will produce a swing exactly equal to that effected by the standard charge is then found by the following equation:

The average swing produced by the explosive under test : the average swing effected by the standard dynamite = the actual weight of the explosive under test : the unit deflective charge.

The unit deflective charge thus determined is the unit charge used in tests 1, 2, and 3 in gas and dust gallery No. 1.

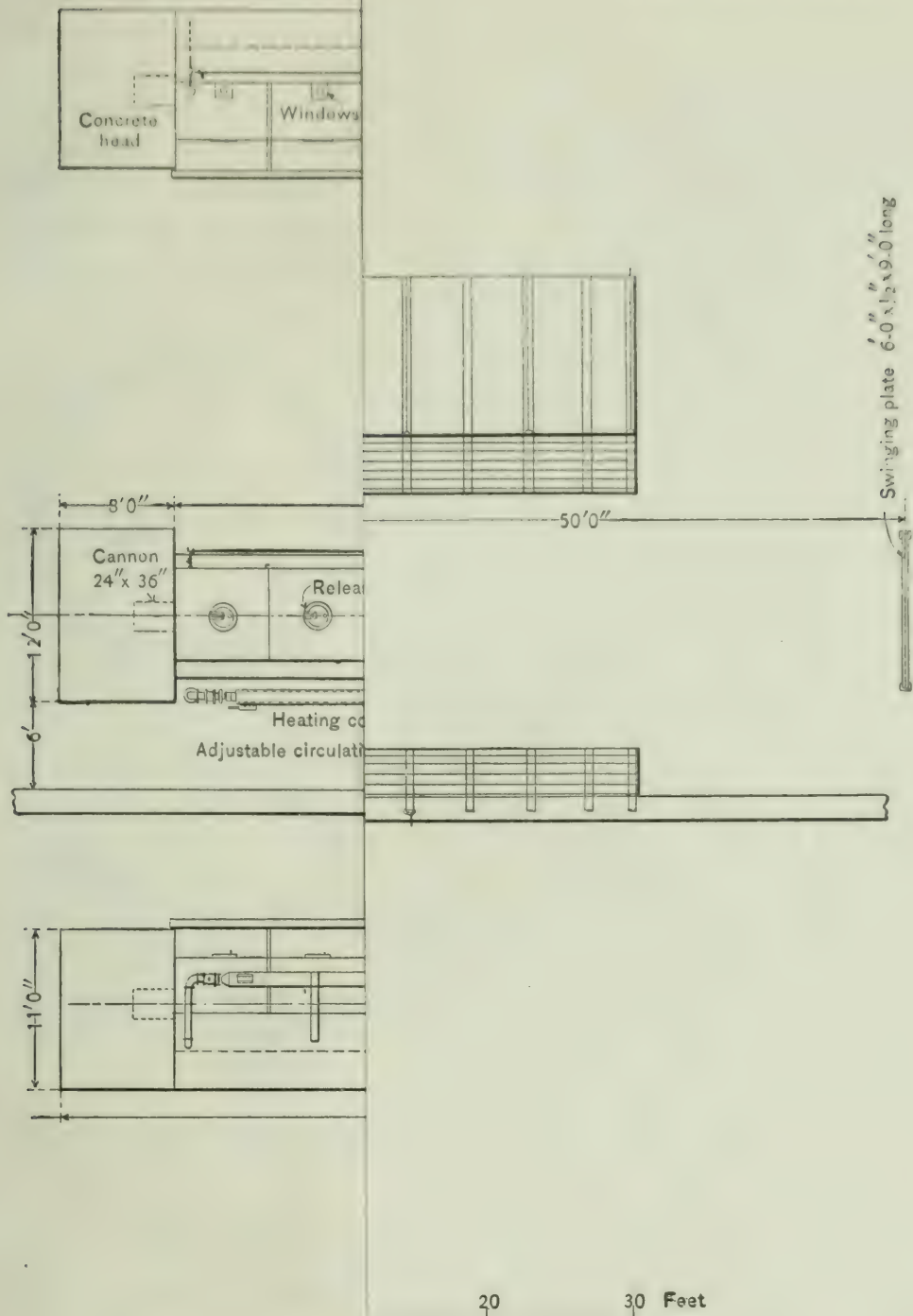
GAS AND DUST GALLERY NO. 1.

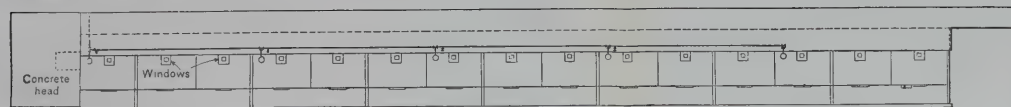
Gas and dust gallery No. 1 (Pls. IA, and II) is designed for the purpose of ascertaining the effects of explosives when fired under known conditions into explosive mixtures of mine gas and air, of coal dust and air, or of mine gas, coal dust, and air. A further purpose is the ascertaining of the extent to which water vapor, incom-bustible dusts, or other substances may diminish the inflammability of such mixtures, or may delay or prevent the propagation of explosions within them. Other logical uses of such a gallery will be apparent.

The gallery simulates a gallery or room within a coal mine, and the gun chamber in which the explosives are fired simulates a bore hole in the coal or rock of such a mine.

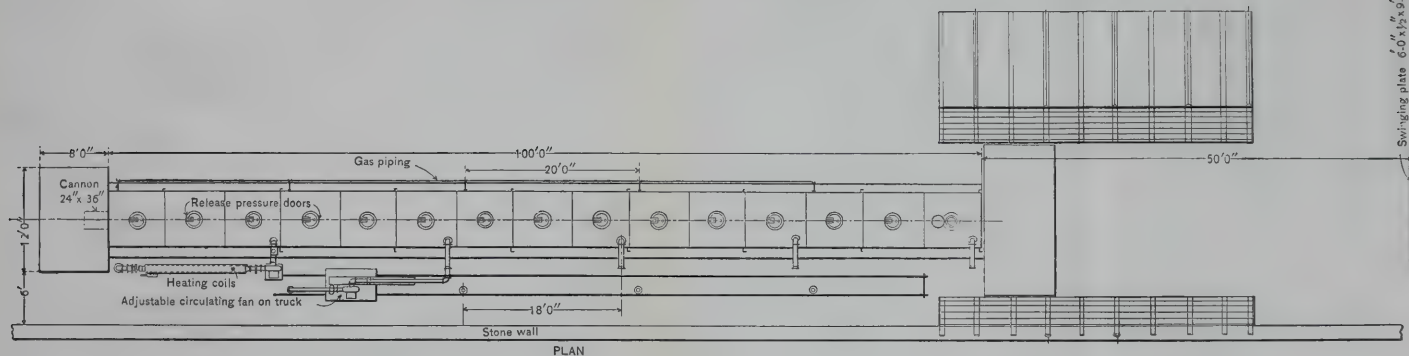
The gallery is a cylinder 100 feet (30.48 meters) in length, with a minimum diameter of $6\frac{1}{2}$ feet (1.93 meters), and is closed at one end by a concrete head. It is built of boiler-plate steel in five divisions, each consisting of three similar sections. Each section is $6\frac{2}{3}$ feet (2.03 meters) long, and is built up of in-and-out courses.

The different sections of the gallery are, for convenience, numbered consecutively from 1 to 15, beginning with the section nearest the concrete head. Sections 1, 2, and 3 are made of $\frac{1}{2}$ -inch (1.27-centimeter) steel plates; sections 4 to 15 inclusive are made of $\frac{3}{8}$ -inch (0.95-centimeter) steel plates. The tensile strength of the steel used is not less than 55,000 pounds per square inch (3,867 kilograms per square centimeter). The tubes forming each section are held together by lap joints. On the interior of the gallery there is at each lap joint a $2\frac{1}{2}$ -inch (6.4-centimeter) circular angle iron, forming a ring around the gallery. By means of semicircular washers, studs and wedges, a paper diaphragm may be so secured to these angle

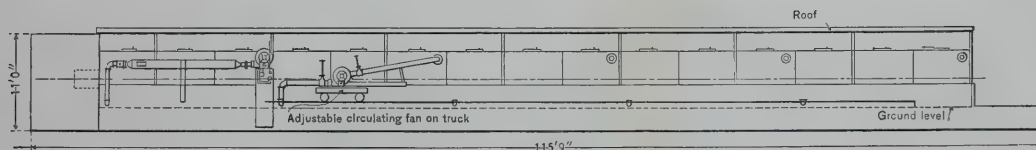




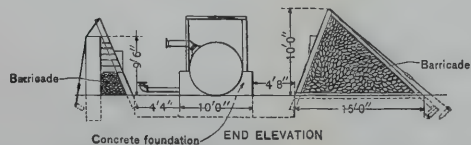
FRONT ELEVATION



PLAN



BACK ELEVATION



0 10 20 30 Feet

PLAN, AND FRONT, BACK, AND END ELEVATIONS OF GAS AND DUST GALLERY NO. 1.

Swinging plate 6'-0" x 1/2" x 9'-0" long

which samples of the gas-air mixture, with which the gallery is charged, may be drawn for analysis.

The gallery rests on a reinforced concrete foundation which is 10 feet (3.05 meters) wide and 2 feet (0.61 meter) thick at the center, but it is carried up $4\frac{1}{2}$ feet (1.37 meters) on the sides of the gallery where it is finished off with a coping. A narrow gutter cut in the concrete extends under the gallery for its entire length and, in connection with 1-inch (2.54-centimeter) holes opening into it from each section of the gallery, insures an effective means of drainage. These holes are closed by plugs when the gallery is in use.

Sections 1, 2, and 3 are covered with an insulating jacket to assist in maintaining at constant temperature any gas-air mixture within the gallery. This jacket is made up of magnesia-asbestos blocks, asbestos cement, a layer of 6-ounce duck, and strips of waterproof roofing paper. The jacket as a whole is treated with a thick coat of graphite paint.

The explosives are fired in a cannon which is embedded in the concrete head of the gallery in such a manner that the axis of its bore coincides with the longitudinal axis of the gallery. The cannons used are cylinders 24 inches (61 centimeters) in diameter by 36 inches (91.4 centimeters) long, and they each have a bore hole $2\frac{1}{4}$ inches (5.72 centimeters) in diameter and $21\frac{1}{2}$ inches (54.6 centimeters) deep. In constructing them, various methods and materials have been used in an endeavor to make cannons which would best resist the shattering and erosive effects of the explosions. The simplest cannon was made in one piece by boring out a low-carbon or nickel-steel forging to form a chamber or bore hole of the desired size. In another form of construction, illustrated in figure 3, the cannon consists of a cast-steel jacket surrounding a chambered liner of forged nickel-steel. The nickel steel used in these liners contains from 1.5 to 3.5 per cent of nickel.

In a built-up cannon the jacket is a hollow cylinder, 36 inches (91.4 centimeters) long, 24 inches (61 centimeters) in external diameter, $9\frac{1}{2}$ inches (24.1 centimeters) in internal diameter for a distance of $28\frac{1}{4}$ inches (71.8 centimeters) from one end, and $7\frac{1}{2}$ inches (19 centimeters) in internal diameter for the remainder of its length. The liner is made to fit the hole in the jacket, but it is $36\frac{3}{4}$ inches (93.3 centimeters) long, and when the parts are assembled its smaller end extends three-fourths of an inch (1.9 centimeters) beyond the jacket.

In assembling these built-up cannons, the jackets are shrunk on the liners.

The concrete head, which completely closes one end of the gallery, is 11 feet (3.35 meters) high, 12 feet (3.66 meters) wide, and 8 feet (2.44 meters) long. The iron shell of the gallery is embedded 3 inches (7.6 centimeters) in the concrete head and is tied to it by

means of eight barbed anchor bolts each 8 feet (2.44 meters) long and $\frac{3}{8}$ inch (15.9 millimeters) in diameter, running from angle irons riveted to the shell.

The concrete head is reinforced by many pieces of scrap iron, but especially by four 6-inch (15.2 centimeter) I beams each $10\frac{1}{2}$ feet (3.15 meters) long, placed two on each side of the head and flush with the sides. These I beams are joined in pairs by $\frac{3}{8}$ -inch (9.5-millimeter) rods; each pair by two rods.

The cannon has its muzzle flush with that face of the concrete head which closes the end of the gallery. Directly back of the cannon there are seven cylindrical rubber bumpers, each 6 inches (15.2 centimeters) in diameter and 3 inches (7.6 centimeters) thick. These rubber bumpers are fastened to and held in place by 24 by 24 by 12 inch (61 by 61 by 30.5 centimeter) oak blocks, which are, of course, embedded in the concrete head.

Natural gas ^a is used in making the gas-air mixtures for the gallery. The gas is admitted into the first division of the gallery by means of a

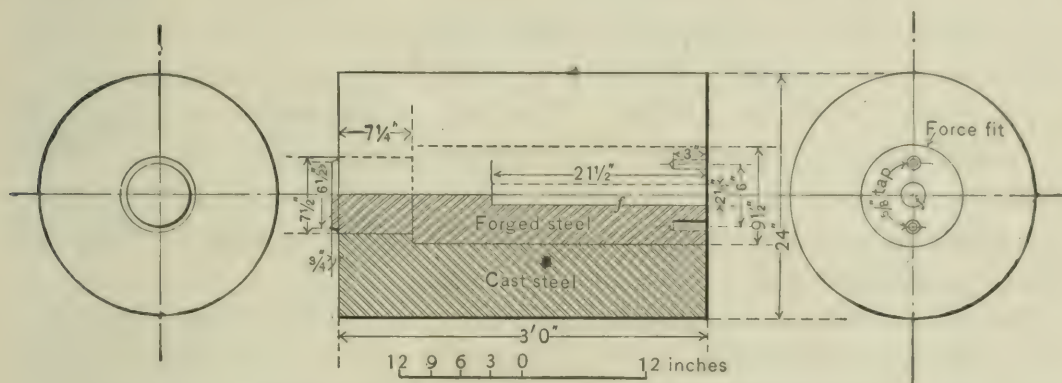


FIGURE 3.—Partial section and end views of built-up cannon.

2-inch (5.1-centimeter) pipe, 14 feet (4.27 meters) long, which is placed parallel to and within $2\frac{1}{2}$ inches (6.4 centimeters) of the floor of the gallery. This pipe is provided with perforations of such dimensions and so placed that an equal flow of gas is maintained throughout each unit length of the pipe. The gas, as it enters the gallery, is measured by means of an accurate test meter which can be read to 0.05 cubic foot (0.0014 cubic meter).

The mixing of the air and gas is effected by circulating systems which are largely exterior to the gallery. The chief feature in each system is a No. 3 Sturtevant Monogram right-handed exhaustor, with bottom horizontal discharge, operated by a direct-connected direct-current motor, having both bearings on one side of the exhaustor and not exposed to the action of the gas. The exhaustor case is rendered gas-tight by a stuffing box through which the shaft passes. The case and flanges are of extra thickness. The circulat-

^a For analysis of the natural gas used at the Pittsburgh station, see p. 66.

ing system for the first division of the gallery is stationary and includes steam-heating coils by means of which the gas-air mixtures may be heated so as to maintain a constant temperature within the gallery. These steam-heating coils are so connected that they may be cut off from the circulating system at will by means of a by-pass into which the current of gas and air may be deflected by means of valves.

Each division of the gallery except the first is served by a common circulating system which is mounted on a truck so that it may be moved from point to point as desired. Each circulating system is provided with two 6-inch (15.2-centimeter) three-way iron stop cocks by means of which they may be cut off from the gallery to protect the exhauster from damage when an explosion takes place.

The interior of the gallery is provided with shelves made of $\frac{3}{8}$ -inch (9.5-millimeter) steel on which to place coal dust. Four of these shelves are placed, one above the other and 8 inches apart, on each side of the gallery, to which they are attached by means of brackets or studs. The shelves are each 20 feet (6.1 meters) long by 4 inches (10.2 centimeters) wide, and they extend in sections of the length given, throughout the gallery. In addition to these shelves a wooden bench or trestle is used for supporting coal dust in the first section of the gallery. The top of this bench is 20 feet (6.1 meters) long and 12 inches (30.5 centimeters) wide, and the height of the bench is such that its top is 9 inches (22.9 centimeters) below the axial line of the cannon and gallery. When used the bench is placed parallel to the sides of the gallery.

The coal dust used is ground to pass a 100-mesh screen by means of a cylindrical cast-iron Abbe pebble mill, whose interior is 26 inches (66.0 centimeters) in diameter and 24 inches (61.0 centimeters) in length. The mill turns on its horizontal axis at the rate of 60 revolutions per minute. It is provided with a 7 by 9½ inch (17.8 by 24.1 centimeter) opening in the side of the cylinder by which the mill may be charged or emptied. This opening is provided with two covers, one of which is solid and the other perforated with ½-inch (12.7-millimeter) holes, the latter being used to retain the pebbles while the coal dust is being emptied out of the mill. This dust is dumped into a hopper, which completely incloses the cylinder of the mill. From this hopper the dust is transferred to galvanized-iron cans in which it is stored until used. When coal is to be ground it is first broken by hand into small pieces, and 60 pounds (27.2 kilos) of these fragments are put into the pebble mill. The mill is started and the grinding is continued for three and one-half hours, when the product is sifted by means of a 100-mesh screen.

In order that quantitative tests may be made of the effect of moisture in preventing the ignition of coal dust or the preparation of explosions in mixtures of coal dust and air, the gallery is equipped

with a humidifying apparatus by which steam or water spray may be injected into the gallery so as to bring its atmosphere at a given temperature to the desired degree of humidity. For this purpose a Koerting exhaustor, having a capacity of 240,000 cubic feet (6,797 cubic meters) of free air per hour, is connected by means of a wooden conduit to the 14-inch (35.56-centimeter) circular doorway in section No. 1. The similar doorway in section No. 15 is used as an air inlet, and it is connected by suitable wooden conduits to compartments containing the steam radiators and the humidifier. These radiators have 310 square feet (28.81 square meters) of heating surface. The wooden box in which they are inclosed is provided with one 10 by 12 inch (25.4 by 30.5 centimeter) hole and with 25 round holes 2 inches (5.1 centimeters) in diameter, through which air enters the box, and a wooden baffle-board, which directs the course of the air about the radiators. The heated air then passes upward to the long, narrow compartment containing the humidifying heads, from which water is sprayed by means of compressed air and when thus moistened the air passes through the opening in section No. 15 into the gallery. Obviously, to operate the humidifying apparatus the mouth of the gallery must be closed. For this purpose, brattice cloth and paper diaphragms are used.

Ten humidifying heads are placed in the compartment, five being arranged on either side, and they are so installed that any or all may be used as desired. They are fed from a water tank, the bottom of whose overflow orifice is $1\frac{1}{2}$ inches (3.8 centimeters) below the discharge point of the head. Compressed air at a pressure of from 55 to 65 pounds per square inch (3.87 to 4.57 kilograms per square centimeter) enters the box by means of a $\frac{1}{2}$ -inch (1.27-centimeter) pipe. Under these conditions each humidifying head will deliver 30 pounds (13.6 kilograms) of water per hour.

As the blast from the gallery when the explosive mixtures are fired is very destructive, two concrete barricades 8 feet (2.44 meters) high, 30 feet (9.14 meters) long, and $3\frac{1}{2}$ and 13 feet (1.07 and 3.96 meters) wide, respectively, at the base are erected on each side of the mouth of the gallery, and a swinging plate 6 feet (1.83 meters) wide, 9 feet (2.74 meters) long, and $\frac{1}{2}$ inch (1.27 centimeters) thick is suspended on a framework directly across and at a distance of 50 feet (15.24 meters) from the mouth of the gallery, so as to arrest any flying stemming or other material that may be blown out of the gallery.

In order to provide a safe position from which the cannon in the gallery may be discharged and from which the phenomena that occur may be watched, an observation room 40 feet (12.20 meters) long and 9 feet 5 inches (2.87 meters) wide is arranged about 50 feet (15.24 meters) distant from and on the left-hand side of the gallery, facing the breech of the cannon. The walls of this room are of brick, 18

inches (45.7 centimeters) in thickness. The line of vision passes through a plate-glass window 37 feet (11.28 meters) long, 6 inches (15.2 centimeters) wide, and $\frac{1}{2}$ inch (1.27 centimeters) thick. This window is protected externally by two projecting wooden guards, each one being 37 feet (11.28 meters) in length and 3 feet (0.91 meter) wide. In this observation room the meter, with which the natural gas is measured, and the electrical firing device, with which the cannon is fired, are installed and the coal dust is stored. A table is also provided for the engineers engaged in conducting the tests.

METHOD OF CONDUCTING TESTS.

All explosives were subjected to five tests, as follows:^a

Test 1.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 2.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburgh bed, 18 pounds of which are placed on shelves laterally arranged along the first 20 feet of the gallery, and 2 pounds placed near the inlet of the mixing system in such a manner that all or part of the dust will be suspended in the first division of the gallery. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 3.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburgh bed, 20 pounds of which is to be distributed uniformly on a horse placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 4.—A limit charge is determined within 25 grams by firing charges in their original wrappers, unstemmed, at a gallery temper-

^a For list of tests approved January 3, 1911, see appendix, pp. 192-193.

ature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburg bed, arranged in the same manner as in test 2. The limit charge is repeated five times under the same conditions before being established.

Test 5.—Same as test 4, except that 2 per cent of methane and ethane is used instead of 4 per cent, and that one shot is fired instead of five.

In tests 1, 2, and 3, 2 pounds of dry fire-clay stemming is used with slow-burning explosives.

Five different methods have been used for charging the cannon, depending in each case upon the class of explosive to be tested and the test to which it is to be subjected. The classification of the explosives employed for this purpose and the methods used are as follows:

Method A.—The method used for all explosives containing nitroglycerin, in which the object of the test is the determination of the limit charge, is as follows: In charging, a primer 2 inches (5.1 centimeters) long is cut from one of the cartridges and retained. The remaining cartridge or cartridges are cut on both sides and across each end and tamped firmly into the bore hole. No additional pressure is exerted after the charge completely fills the bore hole. An electric detonator of the kind and grade recommended by the manufacturer is then inserted in the center of the primer, and the whole is gently pressed against the charge. The condition of the charge is then investigated by the engineer, and care is taken to see that no small particles of the explosive are left in the bore hole in front of the charge.

Method B.—For all ammonium-nitrate explosives which contain no nitroglycerin and with which the object of the test is the determination of the limit charge, the method of charging is the same as that given in method A, except that the cartridges are rolled until soft before being charged, and the tamping is done gently instead of firmly.

Method C.—In the case of all black blasting powders and similar explosives, whether or not the test is for the determination of the limit charge and whether or not stemming is used, the entire charge is tamped firmly, and then the electric igniter is inserted directly in the charge. If stemming is used, 2 pounds of it are put in, 1 pound at a time, and pressed home firmly. The last pound is tamped very hard.

Method D.—In the case of all explosives containing nitroglycerin, but with which stemming is used in the test, the 2-inch (5.1-centimeter) primer is first inserted in the bore hole and the split cartridges tamped firmly in front of and around it. This method presents a plane surface of the explosive to the stemming.

Method E.—All ammonium-nitrate explosives which contain no nitroglycerin, but with which stemming is used in the test, belong to method E. The method of charging them is the same as for method D, except that the cartridges are rolled until soft before charging them, and the stemming is put in gently instead of firmly.

For stemming, plastic milled fire clay, dried to 0.42 per cent of moisture and ground to 20-mesh fineness, is used. The fire clay is used dry because when used wet the maintenance of that uniform percentage of moisture in the clay necessary in comparative test work is impracticable.

The allowable limit of variation in the temperature of the gallery is 10° F. above or below the stated percentage, the aim being to eliminate extreme conditions of temperature. As all tests reported in this bulletin were made during the winter and spring, it was necessary to heat the gas-air mixture used. In tests made during the summer it is necessary to cool the gas-air mixture. Cooling is accomplished by spraying the outside of the gallery with water.

In all tests in which natural gas is used the allowable limits of variation of methane plus ethane in the gas-air mixture is one-quarter of 1 per cent above or below the stated percentage unless the analysis indicates a more sensitive mixture and there is no ignition.

To insure uniformity in mixing the gas and air the following time intervals obtain:

Heating the air in the gallery: This is continued until the temperature in the gallery is well within the allowable range.

Running in the gas: Three minutes for test 1, two minutes for tests 2, 4, and 5.

Mixing the gas and the air: Six minutes for test 1, five minutes for tests 2, 4, and 5.

Starting sampling to turning off fan: One and one-half minutes.

Turning off fan to firing shot: One minute.

No attempt has been made to establish a limit charge above 1,000 grams because of the severe effects upon the cannon.

When natural gas is used in making the mixtures they are confined in the first division of the gallery by means of a large paper diaphragm.

In making tests 1, 2, 4, and 5, the doors are left open in sections 1, 2, and 3, the doorways being closed by means of small paper diaphragms which are held in place by heavy cast-iron washers. All doors are closed but unfastened in making test 3.

Contrary to expectations it has been found that a decrease in the depth of the bore of the cannon does not make any unstemmed test more severe, and that an increase in the diameter of the bore hole up to 3 inches, so long as the surface is not broken or irregular or does not slope abruptly, does not produce less severe conditions. As every shot in the cannon increases the volume of that part of the bore hole which the charge occupies, especially with large charges and with stronger explosives, it becomes a simple matter to always

maintain the diameter of the bore hole at 3 inches (7.6 centimeters) or less by filling the enlarged portion at the back with fire clay and asbestos rope until the remaining volume of the bore hole will no longer hold the charge.

A sample of the gas-air mixture is taken in every test in which natural gas is used. The apparatus for sampling consists of a bottle, a perforated rubber stopper, a rubber tubing, clamps, and a brass tube long enough to reach the center line of the gallery. The sample is taken over water, and the time required is from one to one and a quarter minutes. The gas chemist analyzes this sample and reports the percentage of natural gas therein. An analysis of the natural gas is made every week and the percentage of natural gas in the gas-air mixture is multiplied by the percentage of methane and ethane in the natural gas to get the percentage of methane and ethane in the gas-air mixture.

The result of every trial shot is recorded either as ignition or no ignition. At the trial a record is made of the number of doorways through which flame issued and the number of windows through which flame was seen. In test 3 record is kept of the number of doors that opened and closed, opened and stayed open, or remained closed; and, in all tests in which dust is used, note is made as to whether or not any charred dust has been formed. In the majority of tests no trouble is experienced in distinguishing an ignition from no ignition, as the flame is seen at least half the distance down the gallery, and charred dust is formed when an ignition takes place. However, in testing low explosives, when the limit charges are very small, say 100 grams or less, there is some difficulty in distinguishing ignition from no ignition, so here an arbitrary standard of an ignition has been fixed, which is as follows: When testing small quantities of low explosives, if it is difficult to distinguish an ignition from no ignition, determination should always be made that the flame was seen in at least one more doorway and one more window with the gas-air mixture than with a clean gallery, and, if dust was used in the test, that at least some small quantities of charred dust were formed, before the result of the trial was designated an ignition.

Except with the explosives Masurite M. L. F. and FFF black blasting powder, with which No. 7 electric detonators and electric igniters, respectively, were used, No. 6 electric detonators have been used with all explosives herein reported for the following tests: Ballistic pendulum, gas and dust gallery No. 1, flame, and explosion by influence.

A test was made to determine whether the No. 7 electric detonators would ignite a gas-air mixture containing 8 per cent of methane and ethane. Ignition of the mixture, either when the electric detonator was put in the bore of the cannon or was suspended freely in the mixture, was found impossible.

In order to utilize the gallery to the best advantage in regard to time, it occasionally became necessary when working three shifts of men to run some or all of tests 1, 2, and 3 before the "unit deflective charge" was obtained on the ballistic pendulum, in which event the charge used in these tests was always greater than the "unit deflective charge," as found by experiment.

RATE OF DETONATION APPARATUS.

Provided all other conditions remain the same, the shattering effect of an explosive varies with the velocity with which the explosion wave or explosive reaction travels through the charge of the explosive. In explosives fired by detonation this movement as measured in definite terms of time and length is styled the rate of detonation.

In every explosion, however initiated, the cross-sectional area that the exposed surface of the explosive immediately presents to the exciting cause, or agent, is a most important factor in determining the final effect. In all of the tests of detonating explosives that have been made at the Pittsburgh testing station, mercuric fulminate, or a mixture of this substance with potassium chlorate alone or with other substances, has been used in electric detonators as the exciting cause. To assure the exposure of a definite and uniform area of the explosive to the action of the electric detonator the explosive is placed in tubes of thin sheet iron 42 inches (107 centimeters) in length and $1\frac{1}{2}$ or 2 inches (3.8 or 5.1 centimeters) in diameter. The variations in the diameters of the iron tubes used are permitted in order to meet the requirements of the different explosives to be tested and to allow for the different diameters of the cartridges in which they are furnished for use in blasting.

When the tube has been charged with the desired amount of the explosive to be tested, two copper wires are inserted through perforations in the tube and cartridge file, at a distance of 1 meter apart, so that the column of explosive between these wires is 1 meter long. The copper wires are each led to a recording chronograph. A No. 7 electric detonator is inserted in the tube, in one end of the column of explosive. The tube with its contents is then suspended in the firing chamber, the copper wires are connected up to the recording chronograph, and the electric detonator, which has been connected to a dynamo electric machine, is fired. Of the two copper wires passed through the tube, the one that is nearest the electric detonator is ruptured first. As the explosion wave proceeds through the column of explosive the second wire is eventually reached and ruptured. The time which elapses between the rupturing of the first and second wire measures the rate at which the detonation proceeds through the column of explosive.

The time which intervenes between the rupturing of the first wire by the explosion of the electric detonator and the rupturing of the second wire by the detonation of the last layer of explosive at 1 meter's distance from the first wire is measured by means of the Mettegang recorder shown in Plate IV, A.

The primary components of the Mettegang recorder are a soot-covered bronze drum so connected to an electric motor that it may be caused to revolve at any desired speed up to 105 revolutions per second; a 220-volt direct-current motor provided with a rheostat for controlling its speed; a vibration tachometer so connected to the bronze drum that the number of revolutions of the latter in unit of time are accurately measured for any speed between 50 and 105 revolutions per second; induction coils the primaries of which receive their current from an electric-lighting circuit having a terminal pressure of 220 volts; and platinum terminals placed about 0.25 millimeter (0.01 inch) from the surface of the rotating drum and in circuit with the secondaries of the induction coils, by means of which electric sparks are so projected against the surface of the drum as to disturb its sooty covering and produce tiny bright spots at the point of impact. These spots may be easily perceived by the aid of a microscope attached to the recorder.

The drum is 500 millimeters (19.69 inches) in circumference. The edge of this drum is provided with 500 teeth which may be made to engage an endless screw. A pointer attached to this screw passes over a dial reading to hundredths, thus indicating with great precision the distance intervening between the spots produced on the soot-covered surface of the drum. The drum is provided with six platinum terminals held by an insulated arm that may be so moved as to bring the points within any desired distance from the drum. Each one of these points may be put in series with one of the secondaries of the induction coils while the other end of the electric lead is grounded to the drum through the base which supports it. Only two of the platinum terminals are used in any single firing trial for the determination of the rate of detonation in a given explosive; the other four are held in reserve for future use.

In ascertaining by this method the rate at which detonation once initiated is transmitted through a column or file of an explosive, the electric current used as the medium for transmitting the record is divided into two parts by passing it through two equal lamp resistances each of which, at the Pittsburgh testing station, consists of a series of from 5 to 20 16-candlepower lamps. After independently traversing the cartridge file at the initial and final points, the two leads are jointly connected to one of the poles of the primary of the induction coil through which the current passes to the return conductor. The secondary of the induction coil is then connected

by one pole to the two platinum terminals and by the other pole to the base supporting the drum as described. In the induction coil—as is well known—any change of tension in the primary coil sets up an induced current in the secondary coil, and this mutual induction between the coils results in the production of a higher potential difference at the terminals of the secondary coil, so that sparks of considerable length and intensity may be obtained. In the earlier part of the work at the Pittsburgh station circumstances were such that coils provided with iron cores were used, and all the data for rate of detonation test recorded in this bulletin were obtained with iron-cored coils. By a readjustment of the apparatus, induction coils without iron coils were made to give the desired kind of sparks, and such coils have been used in all subsequent tests made at the station.

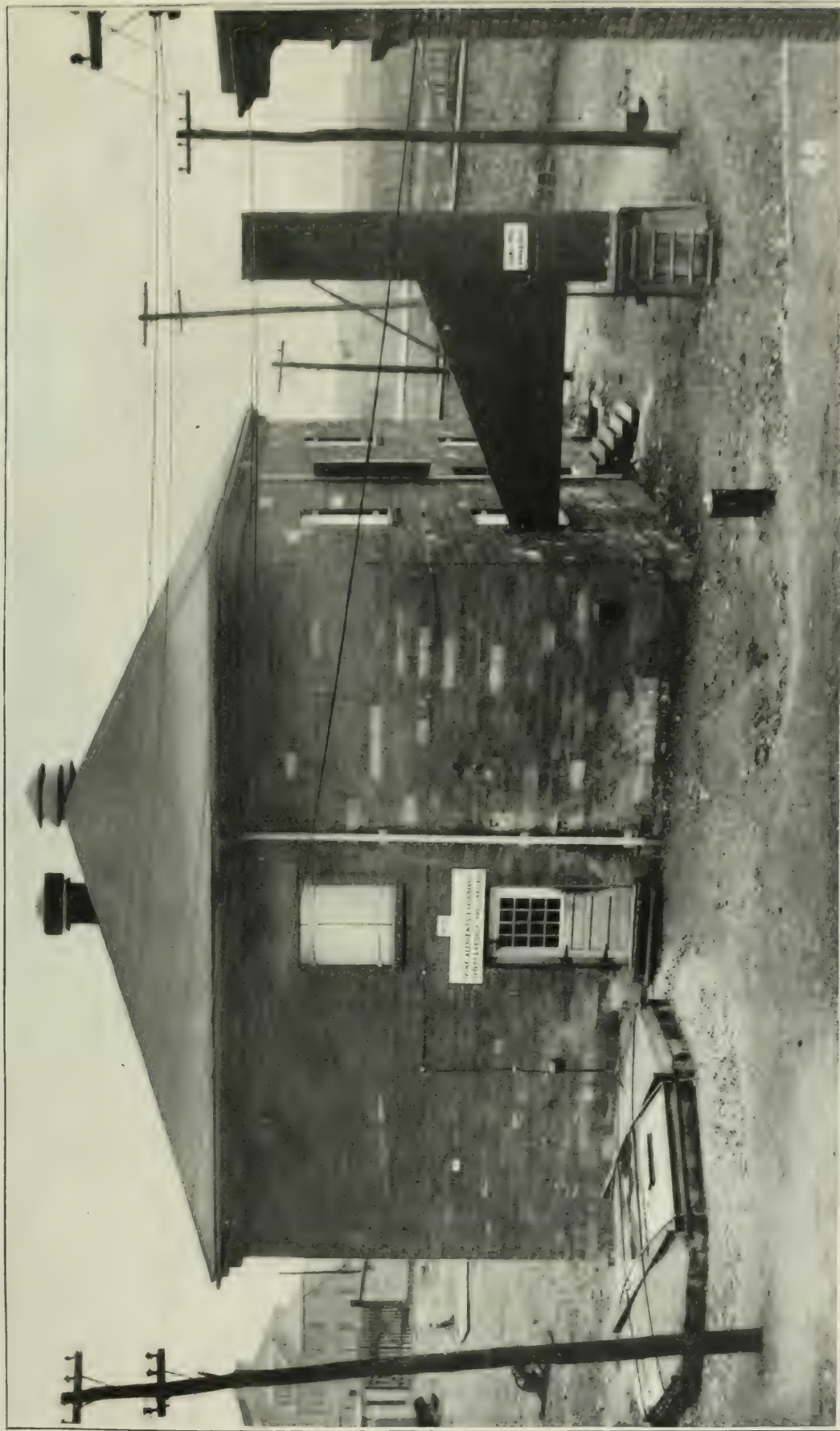
The vibration tachometer, by which the speed of rotation of the drum is measured, is connected to an auxiliary shaft that engages the main shaft of the drum by gears, thus preventing any irregularity in recording the speed due to slipping. This tachometer measures the number of rotations of the drum, but, as the circumference of the drum is accurately known, the distance per second which any point on the periphery travels may easily be calculated. Hence, at the highest speed of 105 revolutions per second, the distance of travel is 52.5 meters (172.2 feet) per second. At 50 revolutions it is 25 meters (82 feet) per second. At 86 revolutions, the number commonly used in the tests at the station, it is 43 meters (141 feet) per second.

The distance between the spots impressed on the surface of the drum are, as has been previously intimated, accurately measured by means of the filar eyepiece and the endless screw, the spots being focused on the cross hairs of the eyepiece.

The iron tube containing the cartridge file is suspended in the chamber whose exterior is shown in Plate III, and the explosive is fired. This chamber is a circular pit that was formerly used as the well of a gasometer. In adapting the pit to its new use the top of the gasometer was cut off and placed at the bottom of the pit on a bed of sawdust and the space between the gasometer and masonry walls of the pit was filled with sawdust. The cover of the pit consists of heavy timbers framed together and overlain with 12 inches (30.5 centimeters) of concrete reenforced by six **I** beams. Four straps extend over the top and down to eight “dead men” planted about 8 feet (2.44 meters) below the surface of the ground. The pit is 16 feet (4.88 meters) in diameter and 11 feet (3.35 meters) deep. A manhole in its cover provides an entrance to the interior.

METHOD OF CONDUCTING TEST.

The rate of detonation is measured through a cartridge file 42 inches (107 centimeters) in length. In making a test the separate



BUILDING 17; RATE OF DETONATION PIT; CYLINDER AND CONDUIT OF FLAME-TEST APPARATUS.

cartridges, having the paper cut from their ends to avoid the damping effect of its folds, are placed end to end in a sheet-iron tube 42 inches (107 centimeters) long and either $1\frac{1}{2}$ or 2 inches (3.8 or 5.1 centimeters) in diameter, depending upon the diameter of the cartridges used. Two copper wires leading from the Mettegang recorder are passed 1 meter (3.28 feet) apart through the cartridge file and firmly secured. The charge thus arranged is suspended horizontally in the pit and exploded by an electric detonator placed in one end of the cartridge file. The drum of the Mettegang recorder is rotated at the desired speed, and the electric detonator is fired by an electric firing device placed near the recorder. As the wires that pass through the cartridge files are broken, spots are formed on the drum the distance between the spots at a constant speed of the drum being proportional to the time elapsing between the breaking of the wires. When the peripheral speed of the drum is 43 meters (141 feet) per second the smallest time interval which it is possible to measure is $\frac{1}{43,000}$ part of a second, although with the distance between wires equal to 1 meter (3.28 feet) such refinement is not necessary.

All high explosives are tested in cartridges having a diameter of $1\frac{1}{4}$ inches (3.2 centimeters). If an explosive with this diameter fails to detonate completely, cartridges having a diameter of $1\frac{3}{4}$ inches (4.4 centimeters) are used. If an explosive should fail to detonate completely with $1\frac{3}{4}$ -inch (4.4-centimeter) cartridges it is considered unsatisfactory and is not eligible for the permissible list.

If the explosive submitted for tests is not in cartridges of $1\frac{1}{4}$ -inch (3.2-centimeter) diameter it is repacked, care being taken that the specific gravity as determined in the physical examination has not been altered.

The rate of detonation, which is expressed in meters per second, is computed from the speed of the drum and the distance between the spark points, as illustrated in the following example:

In the test of Carbonite No. 1 on March 20, 1909, the speed of the drum was 43,000 millimeters per second and the distance between spark spots 12.63 millimeters. Therefore, 43,000 millimeters were traversed in one second, 1 millimeter in $\frac{1}{43,000}$ seconds, and 12.63 millimeters in $\frac{12.63}{43,000}$ seconds. Hence, $\frac{12.63}{43,000}$ seconds is the detonation time for a 1-meter length of the explosive and one second is the detonation time for $\frac{43,000}{12.63}$ meters, or a 3,405-meter length of the explosive.

FLAME-TEST APPARATUS.

The flame-test apparatus is used to record, by photography, the relative lengths and durations of the flames produced by different explosives when they are detonated or fired under the following conditions. The test is based upon the belief that the greater the length of the flame that an explosive emits and the longer the time

during which that flame endures, the more frequent are the chances that such a flame, when shot into the atmosphere of a coal mine, will ignite inflammable or explosive mixtures of mine gas and air, of coal dust and air, or of mine gas, coal dust, and air. That the volume, density, conductivity, specific capacity, and temperature of the flame are, like the length and duration, important factors in determining its effect is recognized, but these must be ascertained and their effects measured by other means. Hence too great emphasis must not be placed on the value of the length and duration of the flame of explosives as an indication of their permissibility, for both the length and the duration of the flames of certain nonpermissible explosives are less than those of some of the permissible explosives, but the other variables, particularly the temperature of the flame, are of importance and must be taken into account. Furthermore, the particular manner in which the air offers resistance to the flame may so laminate and disperse the flame that, in conjunction with other causes, its height and duration may be materially reduced. This air resistance accounts for certain variations in tests of the same explosive.

It is evident that to compare the lengths and durations of different flames they must be measured from a common base line. This measurement may be accomplished by causing the explosion to take place at a certain fixed point and then, by means of a camera, observing the flame constantly at such a point that its apex is included in the field of view. This method is used at the Pittsburgh testing station, and the results that are pictorially set forth in this bulletin show the length and duration of the flames of different explosives. The length of each is indicated by its height in the photograph, and its duration by the length of the photograph.

The apparatus by which the results are obtained consists, essentially, of a cannon for detonating or firing the explosive, and a camera for photographing the flame. Many accessories are needed in order that the test may be successfully made. The most important are the devices employed to cut off all light rays from the camera except those emitted by the flame from the explosive.

The cannon used is identical in shape, dimensions, and size of bore hole with those used in gas and dust gallery No. 1. It is mounted vertically on a concrete foundation at a distance of about 18 feet (5.5 meters) from the lens of the camera. To cut off extraneous light rays it is incased in an iron cylinder, as shown in Plate III. This cylinder is made of $\frac{1}{4}$ -inch boiler plate in twenty-four sections. It is 20 feet (6.1 meters) high and 43 inches (109 centimeters) in diameter. It is provided with a door on one side just above the cannon, which affords an entrance into the interior, and through

which the charging of the cannon is effected. When a test is to be made, the top of this cylinder is closed by covering it with black paper to cut off the sunlight.

The camera is installed in a dark room in building 17, and the cannon, with its stack, is mounted outside of the building. The iron cylinder incasing the cannon is connected to the dark room by means of a 16-foot (4.9-meter) conduit made of sections of $\frac{1}{4}$ -inch (6.35-millimeter) boiler iron, which is rectangular in cross section and made light-tight at all joints, especially where it is riveted to the cylindrical stack that rises about the cannon. The conduit has a width of 12 inches (30.5 centimeters), but, although its bottom is horizontal and its sides vertical, its top inclines from a height of $8\frac{1}{4}$ feet (2.52 meters) above its bottom, at the point where it is joined to the vertical cylinder or stack inclosing the cannon, to 21 inches (53 centimeters) at the point where it ends inside of the wall of the dark room in building 17. At this end, doors are placed in the conduit.

A vertical slit 8 feet (2.44 meters) long and 2 inches (5.1 centimeters) wide is cut in the vertical iron cylinder, or stack, inclosing the cannon, and this slit is so placed that its vertical center coincides with that of the conduit and with the lens of the camera by which it is viewed. The top of the cannon constitutes the base line from which the lengths of the different flames are determined, and therefore the camera is so adjusted and fixed that the top of the cannon always occupies the same position on the field of view of the camera. Hence the height of the flame above the top of the cannon measures the length of the flame produced by the explosive that has been detonated or fired in the cannon.

The duration of the flame is measured by continuously photographing the flame as it appears through the slit in the stack surrounding the cannon. This continuous photograph is taken by making the record on a sensitized film wrapped about a drum that revolves at a determined and known rate of speed within the field of view of the slit in the stack.

The essential features, therefore, of the photographic device employed in this test are: A rotating drum to which the sensitized photographic film is affixed; a 220-volt motor, regulated by a rheostat, by means of which the drum is revolved; a quartz lens by which the rays of light from the flame are focused on the sensitized film; a semicircular shield, in which a stenopaic slit 76 by 1.7 millimeters (3 by 0.067 inches) has been cut, which is placed in front of the lens; a shutter which excludes the light from the photographic box at all times except when the photograph is being taken; and a light-tight box in which all of these parts except the motor are inclosed.

The drum has a circumference of 500 millimeters (19.685 inches) and a height of 100 millimeters (3.937 inches). A beveled gear on the bottom of the axle of this drum engaging with a gear on a shaft from the motor provides a means by which this drum is rotated at a known speed of 20 meters (65.6 feet) per second. The sensitized photographic films used in this test are $3\frac{1}{8}$ inches (98.4 millimeters) wide and 20 inches (508 millimeters) long, and they are so placed on the drum that their ends overlap. These overlapped ends are held in place by gummed strips which are attached to each end of the film, and the films are further secured in the place assigned them by means of heavy rubber bands, which are placed about the top and bottom of the film as it is wound about the drum.

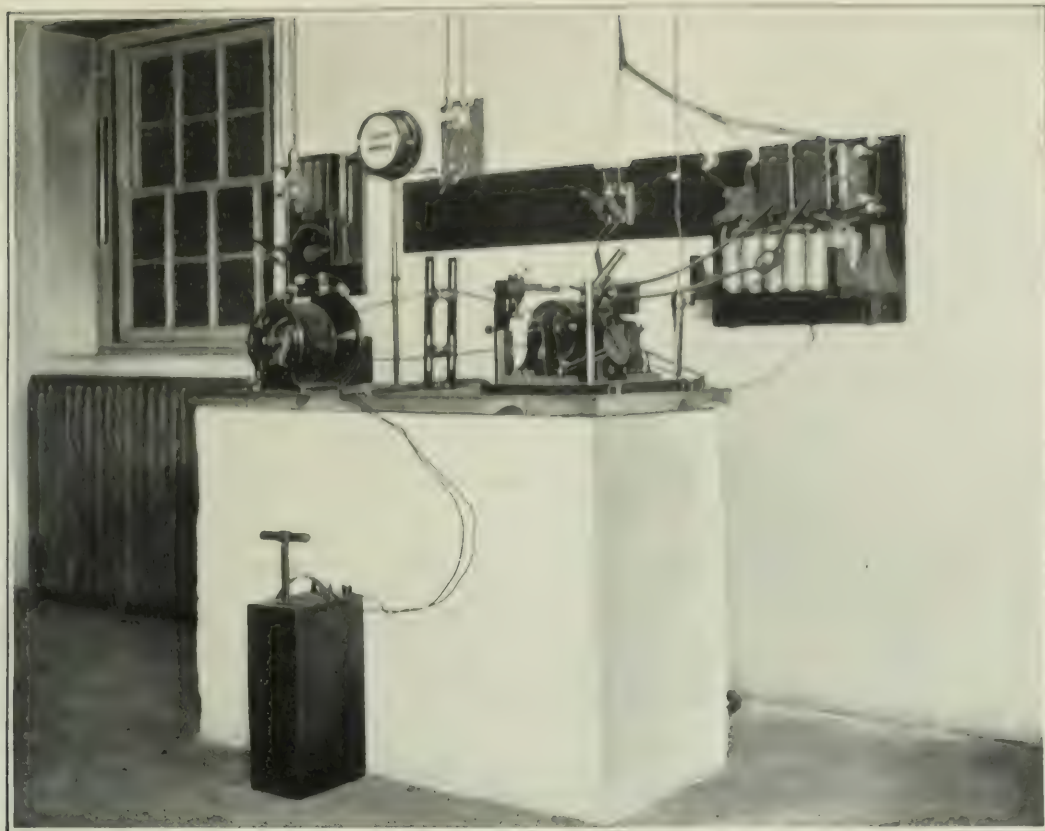
The speed at which the motor revolves is ascertained by means of a tachometer, which is calibrated to read directly in meters per second.

A quartz lens is employed, because it will not only focus the ordinary visible light rays, but also those invisible violet rays that are so largely present in the flames from explosives.

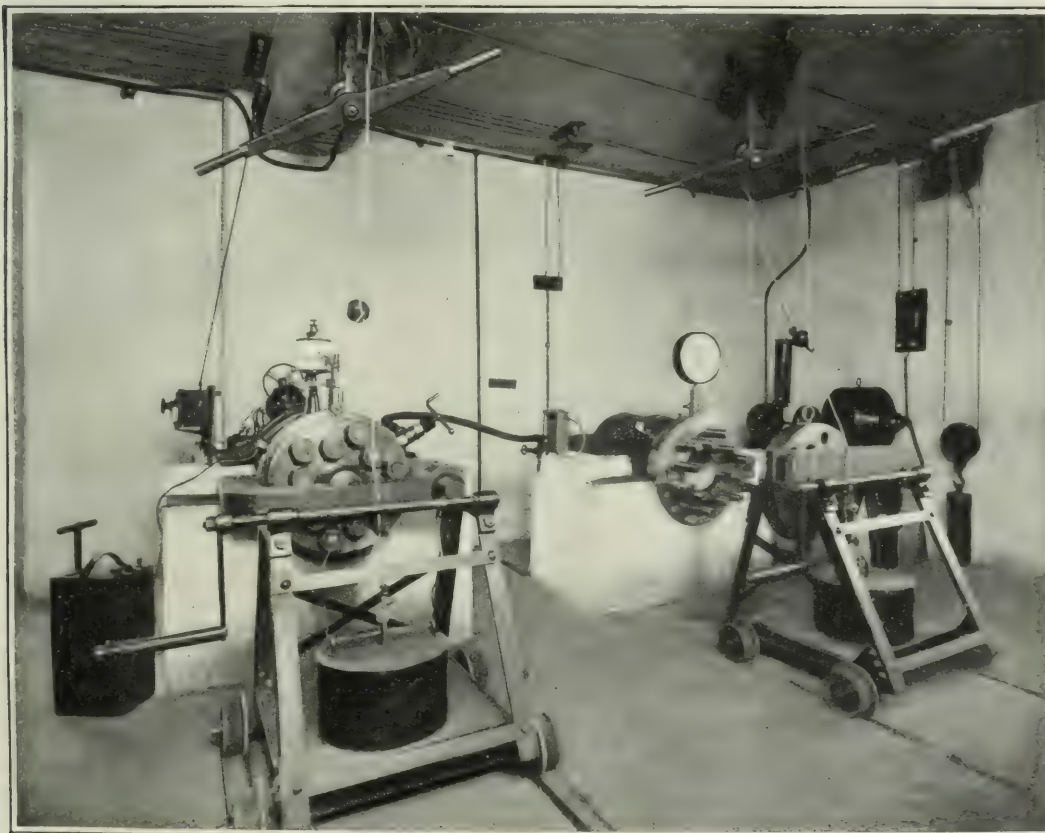
The shutter that eclipses the stenopaic slit and the quartz lens is operated by means of a rubber bulb; it is opened immediately before the shot is fired and closed immediately afterward. A second shutter, at the opening of the conduit from the stack into the dark room, may be opened so as to illuminate the dark room by means of the light coming down the stack, except when the shot is fired. Although this shutter is then necessarily open in order that the flame may be exposed to the camera, the top of the stack is then closed by its paper envelope.

The semicircular shield with its stenopaic slit is placed directly in front of, close to, and concentric with, the drum on which the sensitized film is held, and excludes from the film all rays of light except those from the flame of the explosive.

The tachometer, connected directly to the motor shaft, gives readings not only for the revolutions per minute of the motor, but also readings in meters per second for the peripheral speed of the drum. A maximum peripheral speed of 20 meters (65.6 feet) per second may be obtained for the drum, and this is the speed of rotation that is used in tests of detonating explosives. With slow-burning explosives, however, the duration of the flame is so long that the flame apparently is carried around the complete circumference of the film so many times that the points where the flame begins and ends can not be determined. It is therefore necessary in testing such explosives to run the drum at a much slower speed; to provide for this the apparatus is equipped with an auxiliary shaft and four toothed gears, so that the peripheral speed of the drum is one sixty-fourth of the speed, as shown by the tachometer. For slow-burning explosives this slower speed is quite satisfactory.



A. METTEGANG RECORDER.



B. BICHEL PRESSURE GAGES AND ACCESSORIES.

METHOD OF CONDUCTING TEST.

The charge of explosive used is 100 grams. Shots are fired both with and without stemming. Of the explosives reported in this bulletin only one, namely, FFF black blasting powder, showed any flame when fired with stemming. When stemmed, the charge is loaded in its original wrapper so as to completely fill the bore hole of the cannon. The amount of stemming used is 1 pound, and the method of charging is the same as that for classes C, D, and E given for gallery tests. The electric detonator or electric igniter used, which is of the grade recommended by the manufacturer, is then placed in the center of the charge and the proper electric connections completed.

As high explosives give flames of very short duration, three or more photographs on a single film are taken of the flames from the same explosive, but in no case are photographs of different explosives taken on the same film. The films are developed and prints are made by the official photographer of the Pittsburgh testing station. As some time may elapse between the exposing and developing of the films they are stored in a light-tight tin can sealed with adhesive tape. Occasionally two photographs taken on the same film may so overlap that it is impossible to measure the duration of either one, in which event one or both of the tests must be made again. This accounts for the differences in dates which may be noticed on some records of tests of the same explosive.

When the cannon is charged the engineer retires to the dark room in which the photographic device is located, starts the drum, obtains the desired speed, opens the shutters, and fires the shot by means of an electric firing device. The film when developed shows a figure of certain dimensions. The length and duration of the flame of the explosive is determined from the vertical height and lateral displacement, as shown in the photograph.

In measuring the photograph it is to be recalled that the angle of the lens and its position between the film and bore of the cannon are such that the height of the photograph is to the height of the flame as 1 inch (25.4 millimeters) is to 32 inches (813 millimeters).

The length of the flame is measured in milliseconds or one-thousandths of a second. When the peripheral speed of the drum is 20 meters per second, a 1-millimeter width of the flame is equal to 0.05 milliseconds in time. As the length of the flame is measured to the nearest quarter millimeter, the smallest time interval measured is 0.0125 milliseconds.

On Plate V the upper figure shows photographs of three flames from the same permissible explosive, taken when the film was traveling at a speed of 20 meters (65.6 feet) per second; the lower figures

show the photograph of the flame of a nonpermissible explosive taken when the film was traveling at a speed of $\frac{5}{16}$ meter (1.025 feet) per second.

EXPLOSION BY INFLUENCE.

The test for explosion by influence is to determine the sensibility of an explosive to the explosion wave produced by the detonation of a mass of the same explosive. The column of explosive with which a drill hole is charged is fired by the explosion of the primer or cartridge in which the detonator is put. The charge of a drill hole consists of the explosive that has been put into it, together with the primer and its contained detonator or, as this latter combination is called, its priming charge. In loading a drill hole it may happen that one or more of the successive cartridges inserted in the hole are separated either because the paper covering a cartridge has stripped off and formed a wad between a cartridge and its successor; because some of the material of the walls of the drill hole has fallen in so as to constitute a plug between the different installments of the explosive; or because, through irregularities in the shape of the bore hole or the size of the cartridges, the latter have not all been brought into contact with one another. Such interruptions of continuity may prevent the complete explosion of all the cartridges in the drill hole, and this failure of part of the charge to explode may not only lead to incomplete breaking down of the coal or rock but the unexploded part of the charge may give rise to accidents afterwards.

METHOD OF CONDUCTING TEST.

Two cartridges of the explosive, each one being $1\frac{1}{4}$ inches (3.2 centimeters) in diameter by 8 inches (20.3 centimeters) in length, are so bound together by wire that they may be suspended vertically, end to end, at a carefully measured distance apart. The weights of these cartridges naturally vary with the explosive used, but in repacking the explosive, when necessary, into cartridges of the dimensions given above, care is taken to secure for the explosive the same specific gravity as that found by the sand method for the explosive when it was in the cartridges delivered by the manufacturer. Consequently the cartridges of any given explosive will be of equal weight. An electric detonator of the grade recommended for use with the explosive by its manufacturer is inserted in the lower end of the lower cartridge and secured in place. The whole system is then suspended in the firing pit (Pl. III) and the charge fired. By proceeding tentatively the distance between cartridges at which the upper cartridge is detonated by the lower one is established within 1 inch (25.4 millimeters). For a result to be accepted it must be confirmed by three trials.



A. FLAMES OF A PERMISSIBLE EXPLOSIVE



B. FLAME OF A NONPERMISSIBLE EXPLOSIVE.

THE IMPACT MACHINE.

The impact machine (Pl. VI, A) is used to determine quantitatively the sensitiveness of explosives to explosion when they are struck by a known mass of steel moving at a known velocity while the explosive being tested rests on a steel surface. Naturally the machine admits of such changes that the sensitiveness to explosion through impact between moving and fixed masses of other metals than steel or other substances, either alike or unlike, may be determined, but only when the sample of explosive that is tested is subjected to a direct blow, such as the blow of a mass falling vertically and striking its anvil or buffer squarely. The machine does not admit of determining the sensitiveness of an explosive to explosion when struck tangentially, or, in the vernacular, "a glancing blow."

The machine consists essentially of a framework of steel rods which rise vertically from a massive iron base resting on a concrete pier. A steel rod 57 inches (1.45 meters) high and 2.25 inches (57.2 millimeters) in diameter constitutes the backbone or fundamental element of the structure. In front of this are two rods, between which the yoke and impact weight, or hammer, move. To the right of these, as one faces them, is a vertically driven threaded rod or precision screw, by which the adjustment of the known weight is effected and its height above the plunger stamp is determined.

Resting on the iron base is a case-hardened steel anvil, on which the charge of explosive to be tested is placed. This anvil is surrounded by a tubulated jacket, through which water of known temperature may be circulated. Thus the temperature of the anvil, and hence the temperature of the explosive resting on it, may be brought to a definite temperature.

Above the anvil and between the guide rods is a plunger stamp made of soft steel, which is held in place above the anvil on which it rests by a steel guide which forms a part of the base support for the vertical guide rods.

The steel hammer, whose fall determines the impact, is a cylinder of steel of known dimensions and weight. It is placed above the plunger and between the guide rods. Above it is a yoke that moves freely, up and down, upon the vertical guide rods. This yoke is provided with jaws so placed that the lugs on an endless chain, moving in a vertical cycle behind the yoke, may engage them, and thus the yoke, and any weight attached to it, may be raised to any desired height. By the aid of an electric magnet, the yoke may be magnetized or demagnetized at will. When magnetized it will attract and hold the steel hammer, and then the whole system may be raised, by means of the endless chain, to any desired height within the range of the machine; the yoke can then be demagnet-

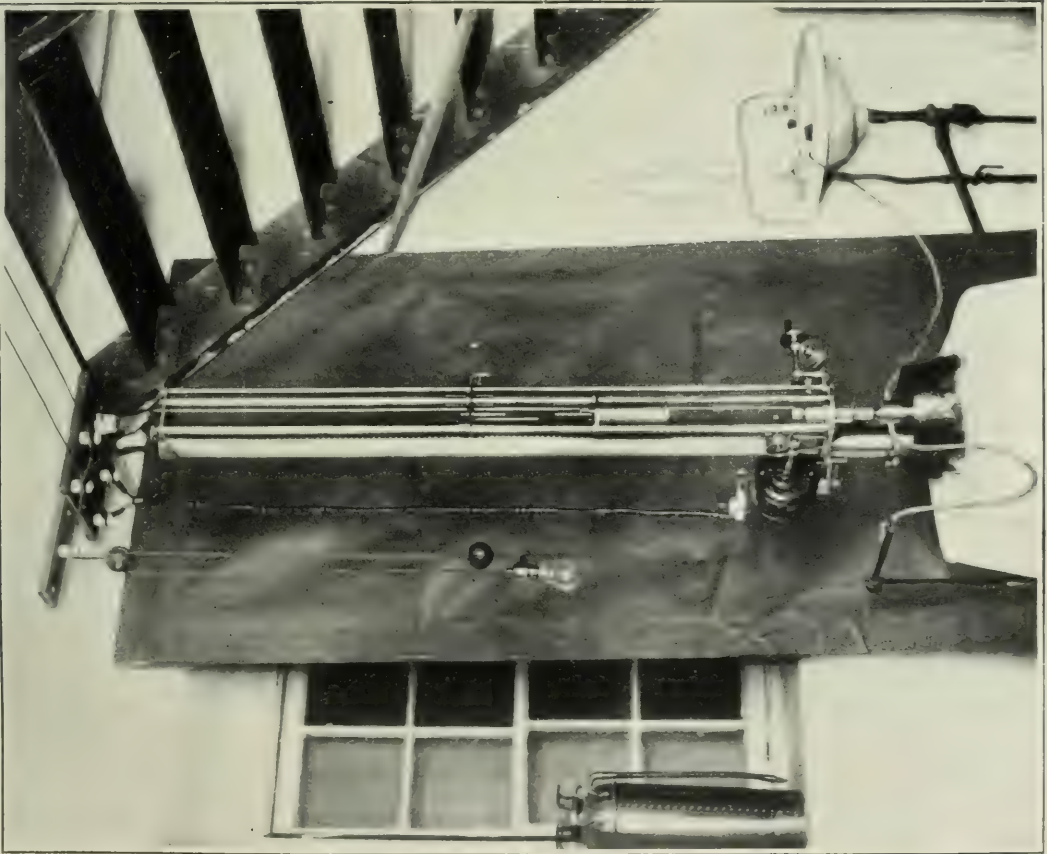
ized at will, causing the release and fall of the steel hammer. The demagnetization may be accomplished automatically by means of a stop set at a predetermined height and provided with a device for arresting the flow of the electric current. The vertically driven precision screw mentioned above raises and lowers the demagnetizing stop, and this screw is geared to a recording device that measures the height from which the steel hammer falls, and hence the distance through which this hammer falls before it strikes the head of the soft-steel plunger, which in turn rests upon the anvil, or, in practice, upon the explosive that rests upon the anvil.

The weight of the hammer used in these tests is 2,000 grams (4.4 pounds). The weight of the soft-steel plunger stamp is 900 grams (1.98 pounds). The plunger stamp is floated with heavy lubricating oil in its guide to insure uniformity in resistance and in movement. The maximum height from which the hammer can be dropped is 100 centimeters (39.37 inches). As the effective impact on the explosive is inversely proportional to the area of the base of the stamp which rests upon the anvil, it is essential that the surfaces of the stamp and of the anvil which face each other shall be perfectly true and parallel, and this is accomplished by turning and grinding them in a precision lathe.

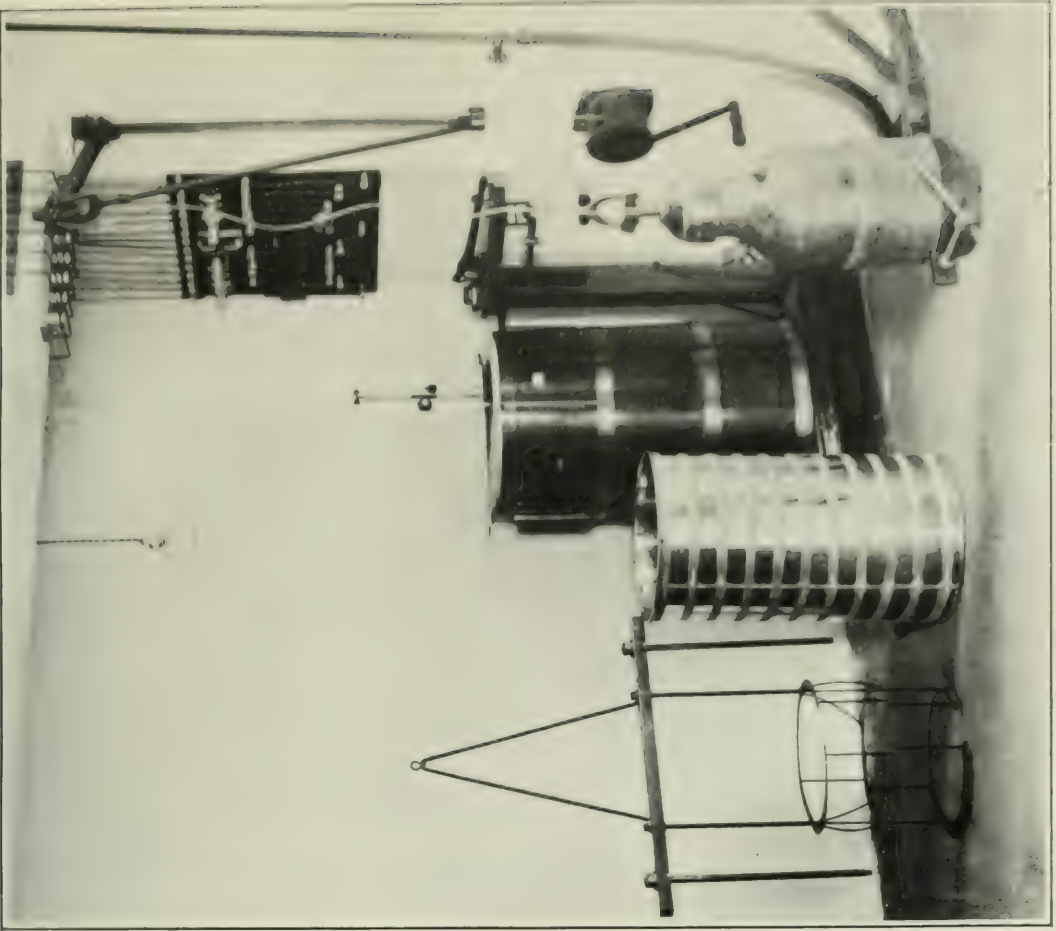
METHOD OF CONDUCTING TEST.

The charge of explosive used in an experiment is 0.02 grams (0.31 grains). This quantity is weighed on a balance, immediately wrapped up in tin foil, and placed in a desiccator (which contains no desiccating material), by which it is protected from the air and in which it is stored and transported until used. The pellet containing the explosive is in the form of a flat disk, having a diameter of 1 centimeter (0.394 inch).

In operating the machine the hammer is raised to a known elevation, the height chosen being selected by judgment. The stamp is lifted, the explosive is transferred from its tin-foil envelope and placed upon the anvil, and the stamp is gently pressed down upon it, so as to insure a good contact of the explosive with the surfaces of the anvil and stamp, and so as to hold the explosive in place. The explosive is allowed to remain in this position for a sufficient length of time to acquire, by heating or cooling, a temperature of 25° C. (77° F.), which is the temperature at which these tests are regularly made at the Pittsburgh testing station. The hammer is then allowed to fall. If no explosion occurs, the weight is raised to successively greater heights until an explosion is effected or the maximum range of the machine is reached. If explosion does occur, successive samples of the explosive are tested at successively lower initial heights of fall. Proceeding thus tentatively, a



A. IMPACT MACHINE.



B. CALORIMETER AND ACCESSORIES.

height of fall is reached such that no explosion follows impact, and yet if the hammer be raised only 1 centimeter above this height an explosion does follow impact. The lesser of these two heights is styled the maximum no-explosion height. This observation is confirmed by four additional trials. Should an explosion occur in these confirmatory trials, the test is repeated by choosing a maximum no-explosion height 1 centimeter less than before, and endeavoring to confirm this height by the four additional trials.

After every trial the anvil and stamp are thoroughly cleaned and a fresh sample is used for the next trial. As the anvil is hard and the stamp comparatively soft, all of the wear due to impact and explosion is on the stamp. A few drops of the hammer suffice to cause the face of the stamp to become flared and pitted. The stamp is therefore removed and trued up by turning and grinding.

THE BICHEL PRESSURE GAGE.

The Bichel pressure gage is employed to determine the maximum pressure that an explosive would exert if exploded or detonated in a space that it fills completely, all of the heat set free by the chemical reactions that take place being retained by the products of the explosion. This is a condition that never exists in practice, for a portion of this heat is always communicated to the walls of the inclosure in which the explosive is fired. As, however, the portion of the heat that is thus communicated is variable, it becomes necessary, in order to directly compare the different explosives tested with one another, to assume theoretical conditions and to provide means by which they may theoretically be attained. Even in the case where the material and cubical content of the chambers in which the explosives are fired is the same the pressures vary with the extent of the surface exposed in the chambers owing to the varying quantity of heat absorbed by the materials of which the chambers are composed. By varying to a known extent the areas of the confining surfaces, it is possible to measure the heat-absorbing effect of surfaces of known area, and, by combining this measurement with the recorded pressure, to estimate the total dynamic effect of the charge of the explosive tested. The result thus obtained is styled the maximum pressure of the explosive in its own volume, a phrase which assumes the existence of purely theoretical conditions.

This apparatus also affords a means for the collection and examination, by chemical and physical methods, of the gaseous, liquid, and solid products of the chemical reactions that take place when the different explosives are fired within it.

The essential features of the apparatus used are the cylinders in which the explosive is fired, the instruments by which the pressure developed in these cylinders is recorded, and the device by which

the heat distribution, or dissipation, is ascertained; but many accessories are needed to render the apparatus operative for the purpose intended.

The apparatus actually employed consists of two stout cylinders, one of which, styled No. 1, has an interior volume of 15 liters (915.345 cubic inches) and the other, styled No. 2, an interior volume of 20 liters (1,220.46 cubic inches). These cylinders are made of cast steel 12.5 centimeters (4.92 inches) in thickness. The heads of the cylinders are provided with gaskets made of lead, and are secured in place by 12 heavy stud bolts and an iron yoke, as shown in Plate IV, *B*. The smaller of the two cylinders has an exterior length of 31.5 inches (80 centimeters); an exterior diameter of 19.75 inches (50.2 centimeters), an interior length of 19 inches (48.3 centimeters), and an interior diameter of 7.875 inches (20 centimeters). The larger of the two cylinders has an exterior length of 31 inches (78.7 centimeters), an exterior diameter of 19.75 inches (50.2 centimeters), an interior length of 25.25 inches (64.1 centimeters), and an interior diameter of 7.875 inches (20 centimeters). A system of sheaves and suspended counterweights is provided to aid in detaching the heavy heads from the cylinders and mounting them upon the specially designed wagons so that access may readily be had to the interiors of the cylinders.

As the air is practically excluded from a bore hole in coal or rock when it is filled with a charge of explosive, these conditions must necessarily be simulated in experimental tests. Therefore the air is almost entirely removed from these cylinders when explosives are fired in them. This is done by pumping out the air until its pressure within the cylinder is reduced to 10 millimeters (0.3937 inch) of mercury.

To accomplish this reduction of pressure a well-glanded tube is inserted in a hole bored in an upper segment of each cylinder near one end, and this tube is connected with a rotary vacuum air pump driven by a 2-horsepower motor. With the device used, only a few moments are required to reduce the pressure in either cylinder to the desired extent. The connecting tube is provided with a valve which, when closed, excludes the outside air from the cylinder.

In the upper segment of the cylinder on the end opposite from the exhaust tube there is a second opening which accommodates the insulated plug that provides a means for conducting the electric current to the electric detonator and also prevents air entering the gage while it is being exhausted or gases escaping after the explosive has been fired and while a considerable pressure exists within the cylinder.

A third perforation is made in the top of each gage and a properly glanded tube inserted in this aperture is provided with a piston

0.3937 centimeter (0.1550 inch) in diameter which can be moved up and down within the tube and is resisted by a spring. Two different springs have been used at the Pittsburgh testing station. One of them exerts a pressure of 1 kilogram per square centimeter (14.22 pounds per square inch) for each 0.4 millimeter (0.015748 inch) of its pencil movement and the other for each 0.56 millimeter (0.022047 inch) of its pencil movement. Careful record of the spring used and its effect is noted in each experiment made.

A stylus is mounted on one end of a lever, the other end of which is fastened to the upper end of the stem of the piston in such manner that while free to move vertically it shall remain in the same vertical plane so long as the gases generated in the cylinder exert pressure upon the piston.

In testing this apparatus many different kinds of oil were used as lubricants about the piston, with the result that it was found that the inertia effects of the piston and the vibration effects in the spring were most completely eliminated when a heavy oil was used. Hence, in all the tests reported in this bulletin heavy cylinder oil at room temperature was used.

Attached to the upper part of each gage and to the rear of the piston rod bearing the stylus is a support carrying a drum on which is a paper ribbon. This drum is mounted so as to rotate horizontally about a vertical axis. The mechanism by which the drum is rotated is geared to an electric motor which runs at a constant speed, and by means of a speed counter the rate of rotation of the drum is accurately measured. Hence the curve drawn upon the indicator card, or paper ribbon, may be resolved with accuracy into its components of horizontal translation of the card and vertical elevation of the stylus at the different periods throughout the explosion. Usually the drum is rotated at a speed of 412 revolutions per minute.

Cylinder No. 2 is constructed in the same manner and fitted with similar appliances, but it is further provided with four solid cast-steel cylinders, which may be introduced into it at will so as to reduce the volume of the chamber while varying its cooling surface. The largest of these cylinders is 17.78 centimeters (7 inches) in diameter and 20 centimeters (7.875 inches) in height. The others are each 17.78 centimeters (7 inches) in diameter and 6.67 centimeters (2.625 inches) in height. Pressure gage No. 1 has a cooling surface of 3,914 square centimeters (607.8 square inches). When the large steel cylinder is inclosed in it pressure gage No. 2 has a cooling surface of 6,555 square centimeters (1016.0 square inches), and when the three small steel cylinders are inclosed in it the gage has a cooling surface of 7,624 square centimeters (1181.7

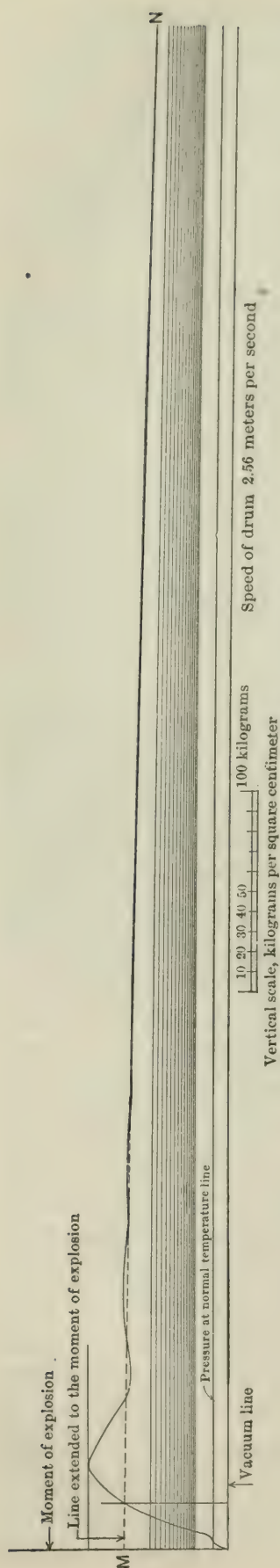


FIGURE 4.—Indicator card from Bichel pressure gage.

square inches). In calculating the results from the observed data, these cooling surfaces are respectively designated A, B, and C in the order enumerated above.

In the center of each gage there is a small wire support upon which the cartridge of explosive is laid, thus preventing the destructive effects on the walls of the gage which an explosive exerts when it detonates in contact with a surface.

METHOD OF CONDUCTING TEST.

The charge of explosive used is 100 or 200 grams (3.53 or 7.05 ounces), according to the character of the explosive as ascertained from a chemical analysis of the substance and from the previous tests in other apparatus. For this test the explosive is removed from its original wrapper and is wrapped in an envelope of tin foil in such a manner that its specific gravity is the same as when it was contained in its original wrapper.

The head of the cylinder is now removed. One leg of a No. 7 electric detonator is fastened to the wire that passes through the insulated plug on the upper segment of the cylinder and the other leg is grounded to the gage through the iron support with which it is in contact. The detonator is inserted and secured in the cartridge and the cartridge laid upon the wire support. The head of the cylinder is then replaced. The cylinder is now exhausted until the internal pressure equals 10 millimeters of mercury, and the motor which operates the drum is set in revolution. When everything is ready the charge is fired by an electric firing device and the indicator record is taken.

Three such tests are made in pressure gage No. 1, and the average result of these is accepted as the pressure existing when cooling surface A is present. Three similar tests are made with cooling surface B and with cooling surface C in pressure gage No. 2.

One of the indicator cards obtained is illustrated in figure 4, where the line M-N, through a portion of its length, indicates the fall of pressure in the gage caused by the cooling of the confined gases. Extending this line to the point marking the moment of explosion of the charge affords only a partial correction for error in the pressure reading due to the cooling of the gases.

However, on inspection of figure 5 it is noted that as the area of the cooling surface is increased the recorded pressure is decreased, and this suggests that the effects of the cooling surfaces may be eliminated and the maximum pressure in each case determined by plotting the pressures against the cooling surfaces. An inspection of the average pressures obtained by this method shows that the points do not lie in a straight line. It therefore becomes necessary to devise

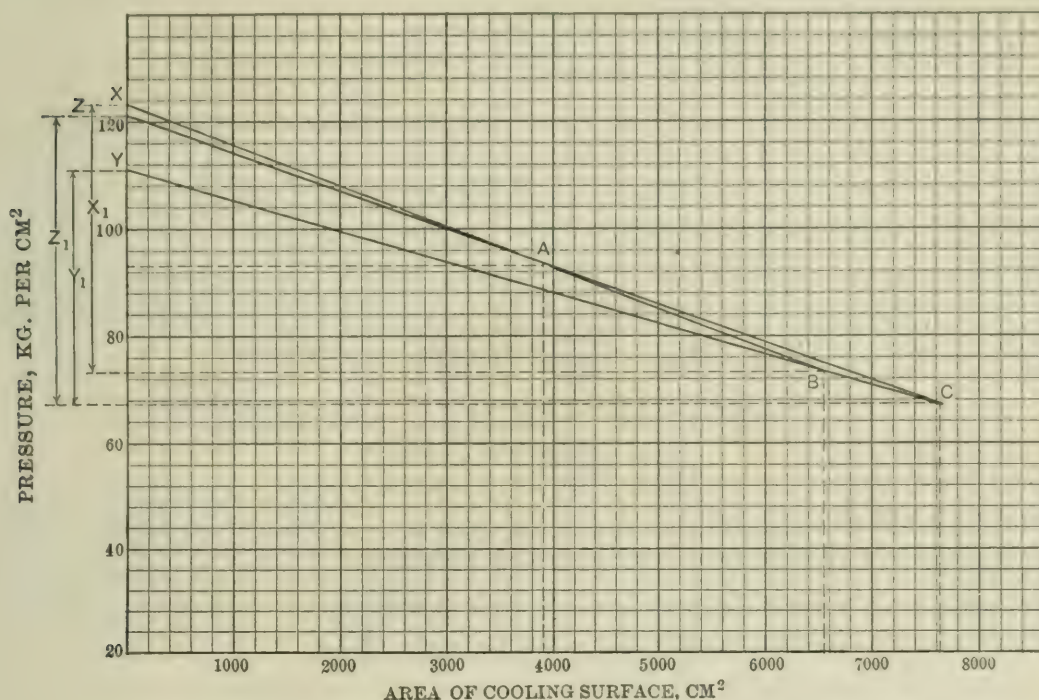


FIGURE 5.—Graphic representation of formula for finding effect of cooling surfaces.

a formula by which to properly proportion the probable errors between these graphic results. The formula adopted and used at the Pittsburgh testing station in the preparation of the results set forth in this bulletin is derived as follows:

Let A=the pressure developed with cooling surface A.

B=the pressure developed with cooling surface B.

C=the pressure developed with cooling surface C.

x =the pressure with elimination of surface influence using A and B.

y =the pressure with elimination of surface influence using B and C.

z =the pressure with elimination of surface influence using A and C.

P=the pressure with elimination of surface influence and probable error.

$x_1 = x - B$.

$y_1 = y - C$.

$z_1 = z - C$.

Then by similar triangles (see fig. 5):

$$x_1 = \frac{6,555 (A-B)}{2,641}$$

$$y_1 = \frac{7,624 (B-C)}{1,069}$$

$$z_1 = \frac{7,624 (A-C)}{3,710}$$

Then, averaging x , y , and z , giving each a value proportional to the difference in cooling surface between the points from which each is derived, and simplifying, gives $P = 1.911A + 0.5B - 1.411C$.

This pressure, P , divided by the charging density, which is defined as the volume of the charge divided by the volume of the gage, gives the maximum pressure of the explosive in its own volume after elimination of cooling-surface influence.

To simplify the computing of the pressure in its own volume, the formula $M = \frac{VPS}{W}$ is adopted, in which M represents the pressure exerted by an explosive, measured in kilograms per square centimeter, when the explosive is exploded in its own volume; V , the volume of the gage in cubic centimeters (this is always 15,000); S , the apparent specific gravity of the cartridge as determined in the physical examination; and W , the weight of the charge in grams.

METHOD OF COLLECTING PRODUCTS.

As has been stated, the Bichel pressure gage, by retaining the products of the explosive reaction, affords a means through which samples of the solid, liquid, and gaseous products may be taken for analysis and investigation, and through which the total quantity of matter in each of these states may be measured.

For this purpose a 200-gram charge of the explosive is fired in pressure gage No. 1. The method followed in preparing and firing the charge is the same as that employed in making the determination of the pressure, except that a Bourdon gage is substituted for the regular indicator mechanism, and that, before firing, the Bourdon gage is isolated from the chamber of the cylinder by closing the stopcock intervening between them. After the explosion the system is allowed to remain in this condition until the products of the combustion have cooled down to room temperature. When the gage no longer shows a decrease of pressure due to cooling of the gas the recorded pressure is noted. At the same time the barometer is read and with the data for temperature, gage pressure, barometric pressure, and volume (which is always 15 liters) the volume of the gases and vapors at 0° C. (32° F.) and at a pressure of 760 millimeters (29.92 inches) of mercury is calculated.

The sample taken of the gases and vapors is drawn out through the valve to which the air pump was attached. It is allowed to escape from the gage slowly by cracking the valve, and a 200 cubic centimeter sample is collected over mercury in such a manner that a differential sample is taken during the entire time of the escape of the gases. In collecting the sample, the mercury in the aspirator is allowed to run out, and the gases and vapors which follow it are drawn off until the pressure within the Bichel gage is reduced to that of the atmosphere. The sample of gases and vapors is necessarily a differential one, as it is drawn slowly and continuously while the pressure in the gage is constantly changing.

To collect and measure the liquid and solid products of the reaction, the head of the cylinder must be removed. The liquid products are then drawn off into a measuring vessel, and the solid products are scraped out and measured, preferably by weight. Of course, this is a rough way of reaching the result, since, among other difficulties, secondary reactions may take place as soon as the air strikes the products, and the material collected may not be identical with that immediately resulting from the reaction. However, no better method appears yet to have been devised. The methods employed for analyzing these products and for ascertaining the effects of the tin-foil wrapper and the components of the detonator on the character and proportions of the components of the reaction products will be described elsewhere.

THE CALORIMETER.

The calorimeter and accessories used at the Pittsburgh testing station are illustrated (p. 102) in Plate VI, *B*. The calorimeter is designed to measure the quantity of heat set free by the explosion or detonation of a known quantity of an explosive. It is constructed on the principles usually followed in calorimeters, by which the chemical reaction is carried on between the reacting bodies while they are immersed in a mass of water of known weight, the temperature of which is raised by receiving the heat set free by the reaction. The difference between the evolution of the heat in an explosion or detonation and that in simple combustion, as, for instance, in the combustion of coal, is one of time only, the rapidity of the reactions in explosion or detonation being greater than in simple combustion.

The apparatus employed consists of a steel bomb in which the explosion takes place; a vessel for holding a measured quantity of water in which this steel bomb is immersed; a wooden tub or cylinder which supports this immersion vessel and also insulates it; a stirring device by which the water in the immersion vessel is so stirred as to distribute the heat evolved throughout the mass of water about the bomb so as to produce a uniform thermal condition; a thermometer

registering a variation of 0.001°C. ; a magnifying glass by which the divisions on the thermometer may be read; a pair of scales on which the parts of the system and the water used may be accurately weighed; and a frame by which the bomb loaded with its charge of explosive may be raised and deposited in place.

The calorimeter bomb is made of wrought steel 0.5 inch (12.7 millimeters) in thickness and is bottle-shaped. It is 30 inches (76 centimeters) in height and 9.5 inches (24 centimeters) in interior diameter in its cylindrical section. It weighs 158 pounds (72 kilograms), has a capacity of 30 liters (1,831 cubic inches), and is closed by a cap which makes an air-tight fit. Two $\frac{5}{8}$ -inch (15.9-millimeter) holes are tapped into this bomb on opposite sides of the neck, near the top. A $\frac{5}{8}$ -inch (15.9-millimeter) valve is screwed and sealed into one side of the neck and is connected by means of a $\frac{5}{8}$ -inch (15.9-millimeter) pipe and flexible rubber hose with a vacuum pump through which the pressure within the bomb may be reduced to 10 millimeters (0.4 inch) of mercury. On the side of the neck opposite that into which the exhaust valve is inserted is an opening through which the plug carrying the detonator and one of its legs is sealed, the other leg of the detonator being grounded to the bomb by means of an iron wire so looped that it can be firmly wedged within the nipple of the valve.

The immersion vessel is made of nickel-plated copper $\frac{1}{16}$ inch (1.6 millimeters) thick. It is $30\frac{7}{8}$ inches (78 centimeters) deep, $17\frac{7}{8}$ inches (45 centimeters) interior diameter, and is strengthened by means of bands of copper wire wound upon the outside. The capacity of this immersion vessel is 7,750 cubic inches (127 liters).

The wooden tub or cylinder in which the immersion vessel is placed is made of wooden staves 1 inch (2.5 centimeters) in thickness and is strengthened by means of four brass hoops on the outside of the cylinder. The vessel has an internal diameter of 21 inches (53 centimeters) and a depth of 33 inches (84 centimeters).

The stirring device consists of a wooden frame supporting three steel rings, which are joined together by rods and stays. When this is adjusted to the calorimeter, the rings fit into the annular water-filled space between the bomb and the inner wall of the immersion vessel, while the exterior rods of the wooden frame run in guides fastened to the exterior of the wooden tub and serve as guide rods when the stirring device is raised and lowered by the electric motor and worm gear which actuates it.

When the parts of the calorimeter are assembled the steel bomb is supported on a steel frame resting on the bottom of the immersion vessel. Likewise the immersion vessel is insulated by means of a wooden support placed upon the bottom of the tub on which the immersion vessel rests. When the apparatus is in use the top of the

tub is covered with a snugly fitting board cover to reduce the loss of heat from the system through radiation.

As stated, the amount of heat given off by the chemical reactions going on in the calorimeter is measured by the rise in temperature of the water in which the bomb is immersed. If the water absorbed all the heat set free, the total number of heat units evolved could be easily determined from the weight and rise in temperature of the water. But manifestly the material of the bomb, the stirring device, the immersion vessel, and the thermometer will each absorb some of the heat, the quantity thus absorbed being dependent in general on the mass and specific heats of the material in each of these devices. It is necessary, therefore, to ascertain in advance the amount of heat that is taken up in this manner, and for convenience the result is stated in terms of the mass of water which is thermally equivalent to the mass of this other material. The result thus stated is styled the water equivalent of the calorimeter. The water equivalent found experimentally for this calorimeter is 11.55 kilograms (25.46 pounds). Furthermore, a certain amount of heat is evolved by the detonator when it is exploded, some of which is taken up by the tin-foil wrapping. Therefore, the heating effect of the detonator is also determined. The No. 7 detonators used at the Pittsburgh testing station develop 0.86 caloric.

Another effect to be noted in calorimetric work is the loss of heat by radiation into the atmosphere when the air is at a lower temperature than the system or the gain of heat from the atmosphere when the latter is at a higher temperature than the apparatus. To prevent any marked changes due to atmospheric influences, the calorimeter is installed in a small insulated room in building No. 17, and then, before firing, the temperature of the water is brought closely to that of the room. As the weights of explosive used and water taken are such that the final change in temperature of the water is less than 1.5°C . (2.7°F .), the error from this source is small, but it is corrected in the data tabulated under "rise in temperature."

METHOD OF CONDUCTING TEST.

The explosive is carefully removed from its cartridge so as to prevent any of its paraffin coating from becoming mixed with it and so as to retain its moisture content and the proportions of the ingredients of the mixture intact. A carefully weighed charge of 100 grams of the explosive, together with a No. 7 electric detonator, is then enveloped in 3.8 grams of tin foil so as to form a cartridge. This cartridge is suspended in the center of the bomb by passing one of the legs of the detonator through the side plug of the bomb and grounding the other leg to the bomb itself in the manner previously described.

The cap of the bomb is then screwed firmly into place so as to make an air-tight joint, and the air within is exhausted by means of the vacuum pump described under the Bichel pressure gages, until the pressure within the bomb is reduced to 10 millimeters (0.4 inch) of mercury. The bomb is placed in the immersion vessel, which, with the tub, thermometer, and stirrer, is resting on the scales, and the weight is noted. Water is then poured into the immersion vessel until the bomb is totally submerged, when the whole is weighed again, the increase in weight representing the added water. The cover is put on the tub and the stirrer is moved up and down until the temperature of the water becomes constant. Then the charge is fired electrically, and, with the stirrer still in operation, the rise of the mercury in the thermometer is noted up to the maximum.

In all computations the following formula is used:

$$C=10[T(W+We)-0.86]$$

in which C=large calories developed per kilogram of explosive.

T=rise in temperature in degrees centigrade after correcting for radiation.

W=weight of water in calorimeter in kilograms.

We=water equivalent of calorimeter in kilograms.

0.86=heat evolved by a No. 7 electric detonator, in large calories.

10=number of 100 grams in 1 kilogram.

The following data from a test are given in full to show what observations are made and the method of computing the result:

Date: April 9, 1909.

Explosive: Coalite No. 2D.

Observer: Hopkins.

Object: To determine the calorific value of the explosive.

Charge: One hundred grams in 3.8 grams tin foil.

Diameter, 3.2 centimeters; length, 10.2 centimeters; volume, 82.01 cubic centimeters.

Electric detonator: No. 7. Absolute pressure: 10 millimeters.

Temperature of room: 18° C.

	Kilograms.
Weight of calorimeter with water.....	251. 58
Weight of calorimeter without water.....	168. 12
Weight of water.....	83. 46
Water equivalent of calorimeter.....	11. 55
Total equivalent water	95. 01
Thermometer used: No. 24.	

Heat developed by a No. 7 electric detonator, 0.86 calories.

Calorimeter readings.

Time.	Temperature.	Difference.	Time.	Temperature.	Difference.
	°C.			°C.	
2.39 p. m.	19.583		3.07 p. m.	20.406	0.823
2.42 p. m.	19.576	0.007	3.12 p. m.	20.406	.000
2.45 p. m.	19.574	.002	3.17 p. m.	20.404	.002
2.48 p. m.	19.570	.004	3.22 p. m.	20.402	.002
2.51 p. m. ^a	19.570	.000	3.27 p. m.	20.400	.002

^a Charge ignited.

$$7.2 \times 0.002 = 0.014 \text{ correction.}$$

$$20.400 + 0.014 = 20.414.$$

$$20.414 - 19.570 = .844 \text{ }^{\circ}\text{C. rise in temperature.}$$

$$95.01 \times .844 = 80.19 \text{ large calories per 100 grams of explosive and detonator.}$$

$$80.19 - .86 = 79.33 \text{ large calories per 100 grams of explosive.}$$

$$79.33 \times 10 = 793.3 \text{ large calories per kilogram of explosive.}$$

SMALL LEAD BLOCKS.

The test with small lead blocks has for its object the determination of the compression effect which detonating explosives produce when they are detonated, unconfined, in close contact with a homogeneous substance which is uniformly compressed by impacts or pressures of equal magnitude. Cylinders of lead have been selected for these tests because the results obtained with them can in a measure be correlated with the results obtained by firing gunpowder and similar explosives in confined spaces, such as the chamber of a gun, for, since Rodman, in 1857, applied this method for measuring the pressures exerted by explosives, the compression test as modified by Woodbridge and Noble has been universally used as a measure of the efficiency of explosives in gun chambers.

There is, however, this difference between the conditions which obtain when explosives are fired in closed chambers with movable pistons, like a gun chamber closed by its projectile, and when explosives are detonated in the open, where the atmosphere acts as the movable piston, namely, that the mass of the piston in the latter case is relatively very small, and in order that its inertia may be made manifest, the chemical reaction that travels through the mass of the explosive must proceed at a relatively high velocity. This capacity of an explosive to produce compression or disruption when it explodes under atmospheric confinement only is designated as the percussive force of the explosive, and is manifest only in those explosives in which the explosion wave travels at so high a velocity that they may be styled high explosives.

METHOD OF CONDUCTING TEST.

The lead blocks are cylinders $1\frac{1}{2}$ inches (3.8 centimeters) in diameter and $2\frac{1}{2}$ inches (6.4 centimeters) in height. They are placed in testing upon a rigid support composed of a large piece of steel shafting, which is embedded in concrete. The standard charge of explosive used in the tests is 100 grams (3.5 ounces), and as this quantity of explosive when detonated would deform the lead cylinder beyond the possibility of accurate measurement, a disk of annealed steel $1\frac{1}{2}$ inches (3.8 centimeters) in diameter and $\frac{1}{4}$ inch (0.64 centimeter) in thickness is placed upon the cylinder in order to receive the immediate effect of the impact. The lead cylinder, therefore, records only the transmitted effect of the explosion.

In preparing the lead cylinder for the test after the steel disk is placed upon it a strip of manila paper is wrapped about and beyond its upper end and secured in such manner as to form a container for the charge of the explosive to be fired. The cylinder is then placed upon the anvil or rigid support; the 100-gram (3.5-ounce) charge of the explosive to be tested is placed in the container on the upper end of the lead cylinder in such a manner as to preserve the specific gravity found for it in the cartridges in which it is offered for use; a No. 7 electric detonator is embedded centrally in the top of the charge of explosive; and, without tamping, the charge is fired. The height of the lead cylinder after the firing is then determined with precision, and this height subtracted from the height of the cylinder before the trial gives the compression caused by the explosion. This result is considered a measure of the relative percussive force of the explosive.

Plate VII, A, illustrates an unused cylinder and disk and cylinders showing the various degrees of compression produced by different explosives.

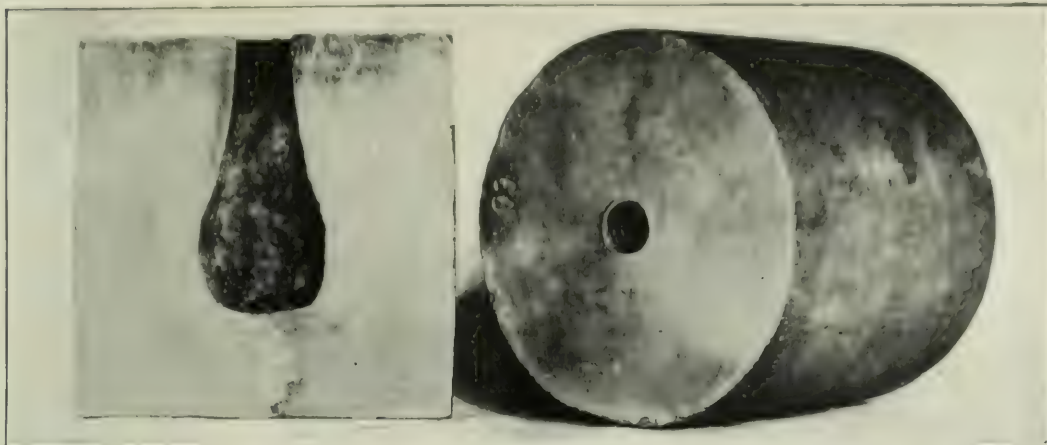
THE TRAUZL LEAD BLOCKS.

The Trauzl test measures the comparative disruptive power of explosives when fired under moderate confinement. In making the test, equal weights of different explosives are confined in bore holes of definite dimensions, made in lead blocks of prescribed character, by means of a fixed quantity of stemming and when thus confined are exploded by means of similar detonators. In this test every effort is made to have each factor alike, except the character of the explosives which are being compared. The measure of the test is the volume by which the cavity in the block is increased because of the pressure exerted by the explosion under the degree of confinement to which the explosive is subjected by the quantity of stemming used, and the firmness with which this stemming is tamped.

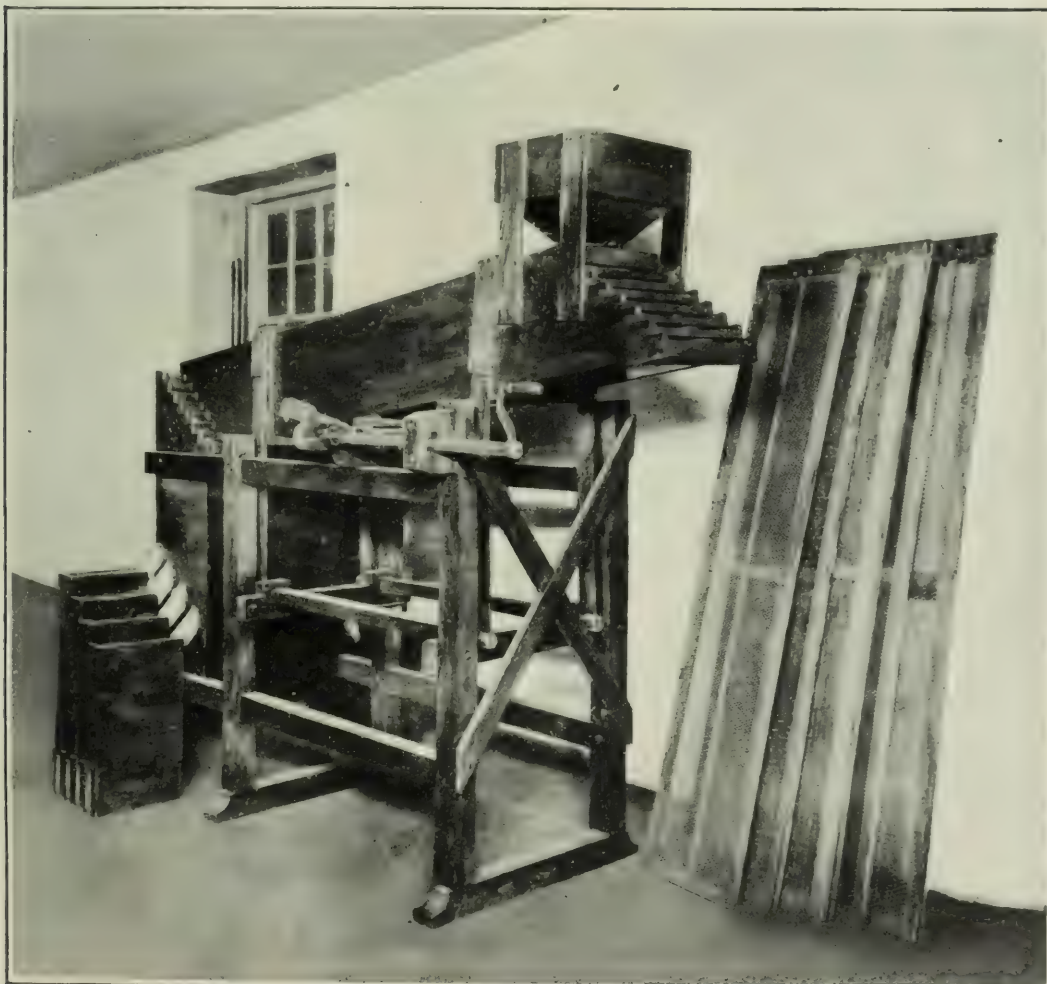
Cylindrical lead blocks 200 millimeters (7.87 inches) in diameter and 200 millimeters (7.87 inches) in height are used. A bore hole 25



A. SMALL LEAD BLOCKS. A, BLOCK BEFORE TEST, B, C, D, E, F, BLOCKS AFTER TEST, SHOWING EFFECT OF DIFFERENT EXPLOSIVES.



B. TRAUZL LEAD BLOCK AFTER TEST, AND SECTION SHOWING EXPANSION OF CAVITY BY EXPLOSIVE.



C. MINIATURE BLACK POWDER SEPARATOR.

millimeters (0.98 inch) in diameter and 125 millimeters (4.92 inches) in depth is made centrally in the upper part of each block. The blocks are cast from desilverized lead of the best quality. Those used in the tests recorded in this bulletin were all made from one mold and the same kind of lead, and were cast under identical conditions, so that the well-known variations which occur in lead from different sources and as cast under different conditions were eliminated.

The material used in stemming was Lake Michigan dune sand containing only a trace of moisture and of such fineness that it passed through a 30-mesh screen and was caught on an 80-mesh screen. Fifty cubic centimeters (3.05 cubic inches) of this sand was used in each test.

The tamping of this stemming is effected by means of an automatic tamping device which operates on the principle of an automatic center punch. The tamping rod used has an area of 284 square millimeters (0.44 square inch). The hammer weighs 470 grams (16.56 ounces) and is actuated through a distance of 285 millimeters (11.22 inches) by a spiral brass spring having an initial tension of 12.7 kilograms (27.94 pounds). This spring is of 10-gage wire (English standard). It has an outside diameter of 52.5 millimeters (2.07 inches), a height of 111 millimeters (4.37 inches), and is coiled in six turns.

Since other investigators in making the Trauzl test have employed plates and yokes of iron with which to further confine the charge, attention is called to the fact that these have not been used at the Pittsburgh testing station. In the preliminary trials it was found that in placing a yoke the charge and stemming were more or less disturbed, and that therefore the initial conditions were not uniform.

METHOD OF CONDUCTING TEST.

The bore hole in the lead cylinder to be used is precisely measured by means of water so as to ascertain its volume in cubic centimeters and cubic inches.

The explosive is carefully removed from its cartridge or container, especial care being taken when the explosive is packed in a paraffined case that no paraffin is mixed with the explosive. A charge of 10 grams (154 grains), weighed on a chemical balance, is used, and this is wrapped in a piece of tin-foil so as to make a cartridge 25 millimeters (0.98 inch) in diameter and about 20 millimeters (0.79 inch) in height, varying with the density of the explosive. The pieces of tin-foil used as wrappers are trapezoidal in shape, the sides having lengths of 150 and 130 millimeters (5.9 and 5.1 inches) and the width being 70 millimeters (2.8 inches). A No. 7 electric detonator is placed in the center of this charge within the wrapper, and the whole is inserted in the bore hole of a lead cylinder. Forty cubic centimeters (2.44 cubic inches) of the dry sand are poured into the bore hole, carefully disposed about

the legs of the detonator, and tamped by 10 blows with the tamping device. Then 10 cubic centimeters (0.61 cubic inches) more of the sand is poured in and tamped with 40 blows from the tamping device. The loaded block is then placed on a rigid support, the temperature is noted to make sure that the temperature of the lead block is 15°C . (77°F .), and the charge is fired. The cavity in the block is then measured with water from a calibrated burette, as before, and thus the increase in volume is ascertained with precision.

The increase in the size of the cavity in a lead block is due to the combined effects of the exploding detonator and the exploding charge. As it has been found that the No. 7 electric detonator when fired in these blocks, surrounded only by dry sand tamped as described, increases the volume by 5 cubic centimeters (0.31 cubic inch), the effect of the detonator may be readily eliminated from the data given.

The appearance of lead blocks after firing is shown in Plate VII, *B*.

THE BLASTING-POWDER SEPARATOR.

The blasting-powder separator (Pl. VII, *C*) is used in determining the relative proportions of different-sized grains in the black blasting powders supplied for use in coal mines. It is similar in form and construction to those used in some mills for grading the grains of powder. In constructing the device care was exercised to introduce no steel or iron parts which might come in contact with the powder.

The apparatus consists of a rectangular wooden box 6 feet 10 inches long, mounted at an angle of 9° from the horizontal on a wooden trestle. The box is provided with a series of slots on its inner sides, into which screens may be slipped. The screens are inserted at the upper end of the box. A wooden hopper, in the form of an inverted truncated pyramid 10 inches (25.4 centimeters) deep, 12 by 16 inches (30.5 by 40.6 centimeters) on the base, and having an aperture 3.5 by $1\frac{1}{4}$ inches (8.9 by 3.2 centimeters), is mounted on the upper end of the box above the set of screens, the top of the hopper being about $6\frac{1}{2}$ feet (1.98 meters) above the floor. It is provided with a sliding brass apron to regulate the feed.

At the lower end of the inclined wooden box is a series of vertical wooden conduits, each being connected at its upper opening to one of the screens. Alongside these vertical conduits and below them is a series of wooden bins, in which the separated powder grains are received. Each vertical conduit is connected by an inclined lateral conduit to one of these bins. Each bin is provided with a sliding gate on the side, near the bottom, so that the grains collected in the bin may be removed.

A rod, with a crank on its end, is mounted on the side of the frame just below the inclined wooden box, and this rod is connected to the box by means of an eccentric device which, when the crank

is turned, causes the box with its contents to move to and fro laterally. By this means the powder is so shaken as to spread the grains out on the screens, cause them to pass through such screens as their sizes permit, and force them, when they can not pass through a screen, to travel down it, and, by the proper conduit, into the proper bin.

The screens consist of light wooden frames, to the bottoms of which are attached the meshed material. The bottoms of the screens having the coarse meshes consist of diagonally perforated zinc plates. The mesh numbers of each of the different zinc plates, perforated with circular holes, together with the diameters of the holes and the numbers of holes per square foot for each mesh number, are set forth in the following table:

Relation between sizes of black blasting powder and separating sieve.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CCC	$\frac{40}{64}$ inch.	$\frac{32}{64}$ inch.
CC	$\frac{36}{64}$ inch.	$\frac{28}{64}$ inch.
C	$\frac{32}{64}$ inch.	$\frac{24}{64}$ inch.
F	$\frac{28}{64}$ inch.	$\frac{20}{64}$ inch.
FF	$\frac{24}{64}$ inch.	$\frac{16}{64}$ inch.
FFF	$\frac{20}{64}$ inch.	$\frac{12}{64}$ inch.
FFFF	$\frac{16}{64}$ inch.	$\frac{8}{64}$ inch.

a Or 28-mesh bolting cloth.

In operating the device a weighed quantity of the powder is poured into the hopper. The sliding brass apron is then set to obtain the desired feed, and the crank is turned until the powder is all separated and the different-sized grains gathered in the different bins. The powder from each bin is then weighed separately. Obviously, all or as many of the screens as desired may be used in any given test.

RATE OF BURNING OF SLOW EXPLOSIVES.

The test for rate of burning of slow explosives is performed under the same conditions as the rate-of-detonation test in that the cartridge file is suspended in the pit outside of building No. 17, the lead wires to the electric detonator and to the copper interrupter wires which pass transversely through the explosive are connected in the same way; and also in that the Mettegang recorder is used to record the time interval.

The explosive is placed in a hydraulic pipe having an inside diameter of $1\frac{1}{2}$ inches, one end of which is filled for 4 inches and the other for 1 inch with plaster of Paris. The latter end is the one that accommodates the electric igniter or electric detonator.

The copper interrupter wires are placed 1 meter apart.

Care is taken that the density of the explosive is normal.

CHAPTER V.

RESULTS OF TESTS WITH PERMISSIBLE EXPLOSIVES.

By CLARENCE HALL and S. P. HOWELL.

ÆTNA COAL POWDER A.

Explosive, Ætna coal powder A.

Class, nitroglycerin.

Manufactured by the Ætna Powder Co.

Physical examination:

Diameter of cartridge, $1\frac{1}{2}$ inches.

Length of cartridge, 8 inches.

Average weight, 205 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.24.

Color of explosive, buff.

Consistency, mixed fibrous and granular; moderately cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date: May 10, 1909.

Unit swing on this date, 2.86 inches.

Weight of charge, in grams, 300, 300, 300

Swing, in inches, 3.07, 3.09, 3.14.

Average swing, in inches, 3.10.

$$3.10 : 2.86 :: 300 : (277).$$

Therefore the unit defective charge of Ætna coal powder A is 277 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
May 10.....	277	8.23	No ignition.	May 14.....	277	.....	No ignition.
Do.....	277	8.23	Do.	Do.....	277	.....	Do.
Do.....	277	8.27	Do.	Do.....	277	.....	Do.
Do.....	277	8.26	Do.	Do.....	277	.....	Do.
Do.....	277	8.15	Do.	Do.....	277	.....	Do.
Do.....	277	8.05	Do.	Do.....	277	.....	Do.
May 11.....	277	8.03	Do.	Do.....	277	.....	Do.
Do.....	277	8.14	Do.	Do.....	277	.....	Do.
Do.....	277	8.14	Do.	Do.....	277	.....	Do.
Do.....	277	7.96	Do.	Do.....	277	.....	Do.
TEST 2.				TEST 4.			
May 11.....	277	4.24	No ignition.	May 13.....	^a 680	4.12	No ignition.
Do.....	277	4.18	Do.	Do.....	^a 680	4.21	Do.
Do.....	277	4.15	Do.	Do.....	^a 680	4.12	Do.
Do.....	277	4.05	Do.	May 14.....	^a 680	4.05	Do.
Do.....	277	4.05	Do.	Do.....	^a 680	4.12	Do.
Do.....	277	4.05	Do.	TEST 5.			
Do.....	277	4.05	Do.	May 14.....	^a 680	2.11	No ignition.
Do.....	277	4.05	Do.				
Do.....	277	4.30	Do.				
Do.....	277	4.12	Do.				

^a 680 grams or more was used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
May 11.....	11. 15	43	3, 857
May 12.....	11. 20	43	3, 839

Average rate of detonation, 3,848 meters (12,620 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
May 22.....	22. 00	27. 79	8. 75	0. 438
Do.....	21. 50	27. 15	9. 50	. 475
Do.....	22. 00	27. 79	9. 00	. 450

Average height of flame, 27.58 inches.

Average duration of flame, 0.454 milliseconds.

IMPACT TEST.

Date, June 29, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	No explosion.	28	1	Explosion.
20	1	do.....	27	3	No explosion.
25	1	do.....	27	1	Explosion.
30	1	Explosion.	26	5	No explosion.

The maximum height at which no explosion occurs established at 26 centimeters (10.24 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
June 12.....	6	Exploded.	June 19.....	7	Did not explode.
Do.....	8	Did not explode.	Do.....	7	Do.
Do.....	7	Do.			

The minimum distance at which no explosion occurs established at 7 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME, AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
June 9.....	200	1.30	28.00	70.00	A	70.42
Do.....	200	1.30	28.50	71.25	A	
Do.....	200	1.30	28.00	70.00	A	
June 17.....	200	1.26	26.50	66.25	B	66.56
Do.....	200	1.22	26.50	66.25	B	
June 18.....	200	1.22	26.88	67.20	B	
Do.....	200	1.22	26.25	65.62	C	64.17
Do.....	200	1.22	25.00	62.50	C	
Do.....	200	1.22	25.75	64.38	C	

$P=1.911A+0.5B-1.411C=77.31$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.24$. $W=200$ grams.

$M=\frac{VPS}{W}=7,190$ kilograms per square centimeter (102,259 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 26, 1909.

	<i>Grams.</i>
Solid.....	57.2
Liquid (water).....	14.0
Gaseous.....	116.8

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
June 23.....	82.13	0.823	762.4
June 24.....	82.13	.786	727.7
Do.....	82.13	.783	724.9

Average large calories per kilogram of explosive, 738.3.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
May 11.....	63.5	47.0	16.5
Do.....	63.5	48.2	15.3
Do.....	63.5	47.2	16.3

Average compression, 16.0 millimeters (0.63 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
June 29.....	62	286	224	29
Do.....	62	284	222	29
July.....	62	295	233	25

Average expansion of bore hole, 226 cubic centimeters (13.79 cubic inches).

ÆTNA COAL POWDER B.

Explosive: Ætna coal powder B.

Class: Nitroglycerin.

Manufactured by the Ætna Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 300 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.10.

Color of explosive, light-buff.

Consistency, mixed fibrous and granular; moderately cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, May 10, 1909.

Unit swing on this date, 2.86 inches.

Weight of charge, in grams, 290, 290, 290

Swing, in inches, 2.81, 2.74, 2.73.

Average swing, in inches, 2.76.

$$2.76 : 2.86 : 290 : (301).$$

Therefore the unit defective charge of Ætna coal powder B is 301 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
May 11.....	301	8.27	No ignition.	May 14.....	301	.....	No ignition.
Do.....	301	8.00	Do.	Do.....	301	.....	Do.
Do.....	301	8.15	Do.	Do.....	301	.....	Do.
May 12.....	301	8.00	Do.	Do.....	301	.....	Do.
Do.....	301	8.00	Do.	Do.....	301	.....	Do.
Do.....	301	8.00	Do.	May 17.....	301	.....	Do.
Do.....	301	8.15	Do.	Do.....	301	.....	Do.
Do.....	301	8.15	Do.	Do.....	301	.....	Do.
Do.....	301	8.15	Do.	Do.....	301	.....	Do.
Do.....	301	8.07	Do.	Do.....	301	.....	Do.
TEST 2.				TEST 4.			
May 12.....	301	4.21	No. ignition.	May 13.....	a 680	4.17	No ignition.
Do.....	301	4.12	Do.	Do.....	a 680	4.05	Do.
Do.....	301	4.12	Do.	Do.....	a 680	3.95	Do.
Do.....	301	4.12	Do.	Do.....	a 680	4.05	Do.
Do.....	301	4.05	Do.	Do.....	a 680	4.12	Do.
Do.....	301	4.05	Do.	TEST 5.			
Do.....	301	3.88	Do.	May 13.....	a 680	2.20	No ignition.
Do.....	301	4.05	Do.				
Do.....	301	4.05	Do.				
Do.....	301	4.12	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.
Electric detonator, No. 7.

Date (1909). '	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
May 13.....	14.00	43	3,071
May 14.....	14.60	43	2,945

Average rate of detonation, 3,008 meters (9,870 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
June 11.....	22.50	28.42	10.50	0.525
Do.....	22.00	27.79	8.25	.412
Do.....	21.50	27.15	9.50	.475

Average height of flame, 27.79 inches.
Average duration of flame, 0.471 milliseconds.

IMPACT TEST.

Date, June 29, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	Explosion.	18	1	Explosion.
15	1	No explosion.	17	1	No explosion.
18	1	Do.	17	1	Explosion.
19	1	Explosion.	16	5	No explosion.

The maximum height at which no explosion occurs established at 16 centimeters (6.30 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 208 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
June 21.....	6	Did not explode.	June 21.....	5	Did not explode.
Do.....	4	Exploded.	Do.....	5	Do.
Do.....	5	Did not explode.			

The minimum distance at which no explosion occurs established at 5 inches.

**THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.**

Indicator spring, 0.4 millimeter = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
June 9.....	200	1.22	26.88	67.26	A	66.78
Do.....	200	1.22	26.75	66.88	A	
Do.....	200	1.22	26.50	66.25	A	
June 18.....	200	1.18	25.00	62.50	B	62.71
Do.....	200	1.18	25.00	62.50	B	
Do.....	200	1.18	25.25	63.12	B	
Do.....	200	1.18	24.75	61.88	C	61.88
June 19.....	200	1.18	24.75	61.88	C	
Do.....	200	1.18	24.75	61.88	C	

$P=1.911A+0.5B-1.411C=71.66$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.10$. $W=200$ grams.

$M=\frac{VPS}{W}=5,912$ kilograms per square centimeter (84,083 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 27, 1909.

	<i>Grams.</i>
Solid.....	65.1
Liquid (water).....	15.4
Gaseous.....	103.9

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
June 24.....	82.13	0.820	759.6
Do.....	82.13	.825	764.3
June 25.....	82.13	.818	757.7

Average large calories per kilogram of explosive, 760.5

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
May 11.....	63.5	49.5	14.0
Do.....	63.5	49.8	13.7
Do.....	63.5	49.8	13.7

Average compression, 13.8 millimeters (0.54 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
June 29.....	62	248	186	29
Do.....	62	254	192	29
July 28.....	62	268	206	25

Average expansion of bore hole, 195 cubic centimeters (11.90 cubic inches).

CARBONITE NO. 1.

Explosive, Carbonite No. 1.

Class, nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 300 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.33.

Color of explosive, drab.

Consistency, granular, moderately cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, February 4, 1909.

Unit swing on this date, 3.01 inches.

Weight of charge, in grams, 260, 260, 260.

Swing, in inches, 3.08 3.04, 2.95.

Average swing, in inches, 3.02.

3.02 : 3.01 :: 260 : (259).

Therefore the unit defective charge of Carbonite No. 1 is 259 grams.

GAS AND DUST GALLERY NO. 1

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Feb. 9.....	259	7.98	No. ignition.	Feb. 6.....	259		No ignition.
Do.....	259	7.97	Do.	Do.....	259		Do.
Do.....	259	7.85	Do.	Do.....	259		Do.
Do.....	259	8.37	Do.	Do.....	259		Do.
Do.....	259	8.17	Do.	Do.....	259		Do.
Do.....	259	8.09	Do.	Do.....	259		Do.
Do.....	259	8.14	Do.	Do.....	259		Do.
Feb. 19.....	259	8.02	Do.	Feb. 10.....	259		Do.
Do.....	259	8.01	Do.	Do.....	259		Do.
Do.....	259	8.08	Do.	Do.....	259		Do.
TEST 2.				TEST 4.			
Feb. 5.....	259	4.02	No ignition.	Mar. 2.....	a 680	4.10	No ignition.
Do.....	259	3.95	Do.	Do.....	a 680	3.93	Do.
Do.....	259	3.94	Do.	Do.....	a 680	4.03	Do.
Do.....	259	3.95	Do.	Do.....	a 680	3.93	Do.
Do.....	259	4.02	Do.	Do.....	a 680	4.18	Do.
Do.....	259	4.09	Do.	TEST 5.			
Feb. 6.....	259	4.09	Do.	Mar. 5.....	a 680	2.01	No ignition.
Do.....	259	4.41	Do.				
Do.....	259	4.08	Do.				
Do.....	259	4.15	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 20.....	12.63	43	3.405
Mar. 23.....	13.15	43	3.270

Average rate of detonation, 3,338 meters (10,950 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Mar. 12.....	20.12	25.41	8.50	0.425
Mar. 19.....	19.75	24.95	8.62	.431
Do.....	19.50	24.63	9.25	.462

Average height of flame, 24.99 inches.

Average duration of flame, 0.439 milliseconds.

IMPACT TEST.

Date, February 5 and 6, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	Explosion.	15	1	Explosion.
15	1	No explosion.	14	2	No explosion.
18	1	Explosion.	14	1	Explosion.
17	3	No explosion.	13	1	Do.
17	1	Explosion.	12	1	Do.
16	1	Do.	11	1	Do.
15	1	No explosion.	10	5	No explosion.

The maximum height at which no explosion occurs established at 10 centimeters (3.94 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 215 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 23.....	5	Exploded.	Mar. 25.....	10	Did not explode.
Do.....	5	Do.	Do.....	9	Do.
Do.....	7	Do.	Do.....	9	Do.
Do.....	8	Do.	Do.....	9	Do.

The minimum distance at which no explosion occurs established at 9 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 11.....	100	1.22	19.50	34.82	A	33.92
Do.....	100	1.22	18.50	33.03	A	
Do.....	100	1.22	19.00	33.92	A	
Mar. 22.....	100	1.18	16.00	28.57	B	29.16
Do.....	100	1.18	16.50	29.46	B	
Do.....	100	1.18	16.50	29.46	B	
Do.....	100	1.18	14.75	26.34	C	27.08
Mar. 23.....	100	1.22	15.50	27.68	C	
Do.....	100	1.22	15.25	27.23	C	

$P=1.911A+0.3B-1.411C=41.19$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.33$. $W=100$ grams.

$M=\frac{VPS}{W}=8,217$ kilograms per square centimeter (116,865 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 4, 1909.

	Grams.
Solid.....	59.1
Liquid (water).....	11.7
Gaseous.....	113.5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Mar. 16.....	83.00	0.817	763.9
Do.....	82.68	.850	792.4
Mar. 25.....	81.90	.816	754.0

Average large calories per kilogram of explosive, 770.1.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 5.....	64.0	49.5	14.5
Feb. 6.....	64.0	50.0	14.0
Do.....	64.0	49.5	14.5

Average compression, 14.3 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic c. c.	Cubic c. c.	Cubic c. c.	° C.
Oct. 16.....	62	222	160	15
Do.....	62	226	164	15
Do.....	62	218	156	15

Average expansion of bore hole, 160 cubic centimeters (9.76 cubic inches).

CARBONITE NO. 2.

Explosive, Carbonite No. 2.

Class, nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 237 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.98.

Color of explosive, light-drab.

Consistency, fibrous, slightly cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, February 19, 1909.

The unit swing used on this date is 3.01 inches.

Weight of charge, in grams, 300, 300, 300.

Swing, in inches, 2.98, 2.95, 3.04.

Average swing, in inches, 2.99.

$$2.99 : 3.01 :: 300 : (302).$$

Therefore the unit defective charge of Carbonite No. 2 is 302 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
Feb. 9.....	Grams. 307	Per cent. 7.91	No ignition.	Feb. 5.....	Grams. 307		No ignition.
Do.....	307	8.49	Do.	Do.....	307		Do.
Do.....	307	8.10	Do.	Do.....	307		Do.
Do.....	307	8.11	Do.	Do.....	307		Do.
Do.....	307	7.91	Do.	Do.....	307		Do.
Do.....	307	7.90	Do.	Do.....	307		Do.
Do.....	307	7.90	Do.	Do.....	307		Do.
Do.....	307	7.82	Do.	Do.....	307		Do.
Feb. 10.....	307	7.99	Do.	Do.....	307		Do.
Feb. 19.....	307	8.18	Do.	Do.....	307		Do.
TEST 2.				TEST 4.			
Feb. 5.....	307	5.03	No ignition.	Feb. 12.....	a 680	4.01	No ignition.
Do.....	307	4.87	Do.	Do.....	a 680	4.00	Do.
Do.....	307	4.07	Do.	Do.....	a 680	3.94	Do.
Do.....	307	3.97	Do.	Do.....	a 680	3.78	Do.
Do.....	307	4.02	Do.	Do.....	a 680	3.90	Do.
Do.....	307	3.97	Do.				
Do.....	307	4.09	Do.	TEST 5.			
Do.....	307	4.09	Do.				
Do.....	307	4.05	Do.	Mar. 4.....	a 680	2.01	No ignition.
Do.....	307	4.14	Do.				

a 680 grams or more were used,

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 18.....	12.22	43	3,519
Mar. 19.....	12.57	43	3,421

Average rate of detonation, 3,470 meters (11,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Millisecond.</i>
Mar. 12.....	15.00	18.95	6.75	0.338
Mar. 19.....	17.00	21.47	7.25	.362
Do.....	17.25	21.79	6.50	.325

Average height of flame, 20.74 inches.

Average duration of flame, 0.342 millisecond.

IMPACT TEST.

Date, March 6 and 8, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	20	1	Explosion.
25	1	Do.	19	1	Do.
30	1	Explosion.	17	1	No explosion.
29	1	Do.	17	1	Explosion.
28	1	Do.	16	1	Do.
27	1	Do.	15	1	Do.
26	1	Do.	14	3	No explosion.
25	1	Do.	14	1	Explosion.
24	1	Do.	13	5	No explosion.
23	1	Do.			

The maximum height at which no explosion occurs is established at 13 centimeters (5.12 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 170 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 19.....	4	Exploded.	Mar. 22.....	6	Did not explode.
Do.....	6	Did not explode.	Do.....	5	Do.
Mar. 22.....	5	Exploded.			

The minimum distance at which no explosion occurs is established at 6 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters = 1 kilogram per square centimeter

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 10.....	100	0.98	19.20	34.28	A	33.74
Feb. 11.....	100	.98	19.00	33.92	A	
Do.....	100	.98	18.50	33.03	A	
Mar. 18.....	100	.93	16.30	29.11	B	29.34
Do.....	100	.93	16.50	29.46	B	
Do.....	100	.93	16.50	29.46	B	
Do.....	100	.93	15.00	26.79	C	27.08
Do.....	100	.93	15.25	27.23	C	
Do.....	100	.93	15.25	27.23	C	

 $P = 1.911A + 0.5B - 1.411C = 40.94$ kilograms per square centimeter. $V = 15,000$ cubic centimeters. $S = 0.98$. $W = 100$ grams. $M = \frac{VPS}{W} = 6,018$ kilograms per square centimeter (85,590 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 5, 1909.	Grams.
Solid.....	57.5
Liquid (water).....	12.0
Gaseous.....	114.7

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Feb. 23.....	81.60	0.751	691.0
Do.....	81.42	.776	712.8
Feb. 24.....	81.30	.797	731.4

Average large calories per kilogram of explosive, 711.7.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 16.....	64.0	51.0	13.0
Do.....	64.0	50.8	13.2
Do.....	64.0	50.8	13.2

Average compression, 13.1 millimeters (0.52 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
Oct. 16.....	62	247	185	15
Do.....	62	246	184	15
Do.....	62	244	182	15

Average expansion of bore hole, 184 cubic centimeters (11.22 cubic inches).

CARBONITE NO. 3.

Explosive, Carbonite No. 3.

Class, nitroglycerin.

Manufactured by E. I. du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 235 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.00.

Color of explosive, light café-au-lait.

Consistency, dry, fibrous.

Unit defective charge as determined by the ballistic pendulum:

Date, February 24, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 330, 330, 330.

Swing, in inches, 3.02, 3.05, 3.10.

Average swing, in inches, 3.06.

3.06: 3.01: : 330: (325).

Therefore the unit defective charge of Carbonite No. 3 is 325 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Feb. 19.....	331	8.35	No ignition.	Feb. 1.....	325	.....	No ignition.
Feb. 27.....	324	8.20	Do.	Do.....	325	.....	Do.
Do.....	324	8.20	Do.	Feb. 2.....	325	.....	Do.
Do.....	324	7.86	Do.	Do.....	325	.....	Do.
Do.....	324	7.92	Do.	Do.....	325	.....	Do.
Do.....	324	7.92	Do.	Do.....	325	.....	Do.
Mar. 1.....	324	8.13	Do.	Do.....	325	.....	Do.
Do.....	324	8.09	Do.	Do.....	325	.....	Do.
Do.....	324	8.16	Do.	Do.....	325	.....	Do.
Do.....	324	8.12	Do.	Do.....	325	.....	Do.
TEST 2.				TEST 4.			
Feb. 1.....	325	4.08	No ignition.	Mar. 4.....	a 680	3.88	No ignition.
Do.....	325	3.89	Do.	Do.....	a 680	3.80	Do.
Do.....	325	4.04	Do.	Do.....	a 680	3.82	Do.
Do.....	324	3.85	Do.	Do.....	a 680	4.13	Do.
Do.....	325	4.01	Do.	Do.....	a 680	4.00	Do.
Do.....	325	4.13	Do.				
Do.....	325	4.09	Do.	TEST 5.			
Do.....	325	4.08	Do.	Mar. 5.....	a 680	2.01	No ignition.
Do.....	325	4.02	Do.				
Do.....	325	4.13	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 11.....	16.33	43	2,633
Mar. 12.....	16.05	43	2,679

Average rate of detonation, 2,656 meters (8,710 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Mar. 11.....	14.25	18.00	6.62	0.331
Do.....	14.00	17.68	6.50	.325
Mar. 16.....	12.50	15.79	6.50	.325

Average height of flame, 17.16 inches.

Average duration of flame, 0.327 milliseconds.

IMPACT TEST.

Date, February 1, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	22	1	Explosion.
25	2	Explosion.	21	1	Do.
23	1	Do.	20	4	No explosion.

The maximum height at which no explosion occurs is established at 20 centimeters (7.87 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 173 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 15.....	8	Did not explode.	Mar. 17.....	3	Did not explode.
Mar. 16.....	6	Do.	Do.....	3	Do.
Do.....	4	Do.	Mar. 18.....	3	Do.
Do.....	2	Exploded.			

The minimum distance at which no explosion occurs is established at 3 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 9.....	100	0.93	16.75	29.91	A	29.17
Do.....	100	.98	16.25	29.02	A	
Feb. 10.....	100	.98	16.00	28.57	A	
Mar. 16.....	100	1.03	15.00	26.78	B	26.93
Do.....	100	1.03	15.25	27.23	B	
Do.....	100	1.03	15.00	26.78	B	
Do.....	100	1.03	14.68	26.21	C	25.55
Feb. 17.....	100	1.03	14.00	25.00	C	
Do.....	100	1.03	14.25	25.45	C	

$$P=1.911A+0.5B-1.411C=33.16 \text{ kilograms per square centimeter.}$$

$$V=15,000 \text{ cubic centimeters.} \quad S=1.00. \quad W=100 \text{ grams.}$$

$$M=\frac{VPS}{W}=4,974 \text{ kilograms per square centimeter (70,742 pounds per square inch).}$$

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 27, 1909.

	<i>Grams.</i>
Solids	75.5
Liquid (water)	12.1
Gaseous	102.3

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Feb. 12.....	80.00	0.783	708.2
Do.....	80.30	.770	698.6
Do.....	80.25	.783	710.2

Average large calories per kilogram of explosive, 705.7.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 1.....	64.0	53.5	10.5
Do.....	64.0	53.0	11.0
Do.....	64.0	53.0	11.0

Average compression, 10.8 millimeters (0.43 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grains.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
Oct. 16	62	218	156	15
Do.	62	220	158	15
Do.	62	216	154	15

Average expansion of bore hole, 156 cubic centimeters (9.52 cubic inches).

CARBONITE NO. 1 L. F.

Explosive, Carbonite No. 1 L. F.

Class, nitroglycerin.

Manufactured by the E. I. du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inch.

Length of cartridge, 8 inches.

Average weight, 305 grams.

Cartridge has been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 1.35.

Color of explosive, café-au-lait.

Consistency, granular, moderately cohesive.

Unit defective charge, as determined by the ballistic pendulum:

Date, February 17, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 300, 300, 300.

Swing, in inches, 2.97, 3.035, 2.96.

Average swing in inches, 2.99.

2.99:3.01::300:(302).

Therefore the unit defective charge of Carbonite No. 1 L. F. is 302 grams.

GAS AND DUST GALLERY No. 1.

Date (1909.)	Weight of charge.	Methane and ethane.	Result.	Date (1909.)	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
Feb. 16	Grams. 330	Per cent. 7.82	No ignition.	Feb. 18	Grams. 302	Per cent.	No ignition.
Do.	330	7.75	Do.	Do.	302	.....	Do.
Do.	330	7.94	Do.	Do.	302	.....	Do.
Do.	330	7.88	Do.	Do.	302	.....	Do.
Do.	330	7.77	Do.	Do.	302	.....	Do.
Do.	330	7.92	Do.	Do.	302	.....	Do.
Do.	330	7.87	Do.	Do.	302	.....	Do.
Feb. 17	330	7.74	Do.	Do.	302	.....	Do.
Do.	330	8.11	Do.	Do.	302	.....	Do.
Do.	330	7.82	Do.	Do.	302	.....	Do.
TEST 2.				TEST 4.			
Feb. 17	302	3.96	No ignition.	Feb. 19	a 680	5.14	No ignition.
Do.	302	4.11	Do.	Do.	a 680	4.06	Do.
Feb. 18	302	4.01	Do.	Do.	a 680	3.99	Do.
Do.	302	3.96	Do.	Feb. 20	a 680	4.16	Do.
Do.	302	4.08	Do.	Do.	a 680	3.92	Do.
Do.	302	4.05	Do.	TEST 5.			
Do.	302	3.98	Do.				
Do.	302	4.01	Do.				
Do.	302	4.01	Do.	Mar. 5	a 680	2.01	No ignition.
Do.	302	4.02	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 27.....	26.81	43	1,604
Mar. 30.....	25.68	43	1,674

Average rate of detonation, 1,639 meters (5,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Millisecond.</i>
Mar. 12.....	12.62	15.94	5.88	0.294
Do.....	11.75	14.84	5.12	.256
Do.....	11.38	14.37	4.38	.219

Average height of flame, 15.05 inches.

Average duration of flame, 0.256 milliseconds.

IMPACT TEST.

Date, February 20, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	21	1	Explosion.
25	1	Explosion.	20	1	Do.
24	1	Do.	19	1	Do.
23	1	Do.	18	1	Do.
22	1	No explosion.	17	5	No explosion.
22	1	Explosion.			

The maximum height at which no explosion occurs established at 17 centimeters (6.69 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 213 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 27.....	8	Did not explode.	Mar. 29.....	4	Exploded.
Mar. 29.....	6	Do.	Do.....	5	Did not explode.
Do.....	4	Do.	Mar. 30.....	5	Do.
Do.....	3	Exploded.	Do.....	5	Do.

The minimum distance at which no explosion occurs established at 5 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 16.....	100	1.26	16.00	28.57	A	28.99
Do.....	100	1.26	16.50	29.46	A	
Do.....	100	1.26	16.20	28.93	A	
Mar. 27.....	100	1.26	15.75	28.12	B	27.68
Do.....	100	1.26	15.25	27.23	B	
Mar. 29.....	100	1.26	15.50	27.68	B	
Do.....	100	1.26	14.75	26.34	C	26.64
Do.....	100	1.26	15.00	26.78	C	
Mar. 31.....	100	1.26	15.00	26.78	C	

 $P = 1.911 A + 0.5 B - 1.411 C = 31.65$ kilograms per square centimeter. $V = 15,000$ cubic centimeters. $S = 1.35$. $W = 100$ grams. $M = \frac{VPS}{W} = 6,409$ kilograms per square centimeter (91,151 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 6, 1909.

	Grams.
Solid.....	62.8
Liquid (water).....	10.4
Gaseous.....	116.5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Mar. 27.....	83.38	0.725	679.6
Do.....	83.28	.727	680.8
Do.....	83.28	.747	699.8

Average large calories per kilogram of explosive, 686.7.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height—		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 24.....	64.0	51.8	12.2
Do.....	64.0	51.8	12.2
Do.....	64.0	52.0	12.0

Average compression, 12.1 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole—		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
Oct. 16.....	62	215	153	15
Do.....	62	215	153	15
Do.....	62	215	153	15

Average expansion of bore hole, 153 cubic centimeters (9.33 cubic inches).

CARBONITE NO. 2 L. F.

Explosive, Carbonite No. 2 L. F.

Class, nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 232 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 0.96.

Color of explosive, light-buff.

Consistency, mixed granular and fibrous; slightly cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, February 18, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 310, 310, 310.

Swing, in inches, 3.01, 3.03, 3.13.

Average swing in inches, 3.06.

3.06:3.01::310:(305).

Therefore the unit defective charge of Carbonite No. 2 L. F. is 305 grams.

GAS AND DUST GALLEY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Feb. 16.....	335	8.44	No ignition.	Feb. 18.....	335	.....	No ignition.
Do.....	335	8.44	Do.	Do.....	305	.....	Do.
Do.....	335	7.87	Do.	Do.....	305	.....	Do.
Do.....	335	7.80	Do.	Do.....	305	.....	Do.
Do.....	335	7.98	Do.	Do.....	305	.....	Do.
Do.....	335	7.88	Do.	Do.....	305	.....	Do.
Do.....	335	8.12	Do.	Do.....	305	.....	Do.
Do.....	335	7.86	Do.	Do.....	305	.....	Do.
Do.....	335	7.95	Do.	Do.....	305	.....	Do.
Do.....	335	7.89	Do.	Do.....	305	.....	Do.
TEST 2.				TEST 4.			
Feb. 17.....	335	4.02	No ignition.	Feb. 20.....	a 680	4.08	No ignition.
Do.....	335	4.08	Do.	Do.....	a 680	3.87	Do.
Do.....	335	4.03	Do.	Do.....	a 680	3.95	Do.
Do.....	335	4.05	Do.	Do.....	a 680	3.86	Do.
Do.....	335	3.96	Do.	Feb. 21.....	a 680	3.80	Do.
Do.....	335	4.01	Do.	TEST 5.			
Do.....	335	3.96	Do.	Mar. 5.....	a 680	2.10	No ignition.
Do.....	335	3.96	Do.				
Do.....	335	4.04	Do.				
Do.....	335	4.07	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 31.....	18.50	43	2,324
Apr. 1.....	17.55	43	2,450

Average rate of detonation, 2,387 meters (7,830 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds</i>
Mar. 29.....	13.25	16.74	5.38	0.269
Do.....	15.38	19.43	6.50	.325
Do.....	14.25	18.00	6.12	.306

Average height of flame, 18.05 inches.

Average duration of flame, 0.300 milliseconds.

IMPACT TESTS.

Date, February 23, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	24	5	No explosion.
25	1	Explosion.			

The maximum height at which no explosion occurs established at 24 centimeters (9.45 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 167 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 30.....	4	Did not explode.	Apr. 2.....	1	Exploded.
Do.....	3	Do.	Do.....	2	Did not explode.
Apr. 1.....	2	Do.	Do.....	2	Do.

The minimum distance at which no explosion occurs established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 17.....	100	0.93	16.50	29.46	A	29.61
Do.....	100	.93	16.75	29.91	A	
Do.....	100	.93	16.50	29.46	A	
Mar. 31.....	100	.93	13.75	24.55	B	25.30
Apr. 1.....	100	.88	14.50	25.89	B	
Apr. 2.....	100	.88	14.25	25.45	B	
Apr. 1.....	100	.84	13.60	24.29	C	24.47
Do.....	100	.88	13.25	23.66	C	
Do.....	100	.88	14.25	25.45	C	

$P=1.911 A+0.5B-1.411C=34.71$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=0.96$. $W=100$ grams.

$M=\frac{VPS}{W}=4,998$ kilograms per square centimeter (71,084 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 6, 1909.

	Grams.
Solid	60.0
Liquid (water).....	12.0
Gaseous.....	117.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Mar. 29.....	82.58	0.740	688.0
Do.....	82.43	.748	694.4
Do.....	82.29	.736	682.1

Average large calories per kilogram of explosive, 688.2.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 24.....	64.0	53.2	10.8
Do.....	64.0	53.5	10.5
Do.....	64.0	53.5	10.5

Average compression, 10.6 millimeters (0.42 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
Apr. 3.....	62	214	152	15
Do.....	62	210	148	15
Do.....	62	207	145	15

Average expansion of bore hole, 148 cubic centimeters (9.03 cubic inches).

COAL SPECIAL NO. 1.

Explosive, Coal Special No. 1.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, $1\frac{1}{4}$ inches.

Length of cartridge, 8 inches.

Average weight, 199.5 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 1.14.

Color of explosive, café-au-lait.

Consistency, mixed granular and fibrous, moderately cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, March 26, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 275, 275, 275.

Swing, in inches, 2.94, 2.85, 2.83.

Average swing, in inches, 2.87.

$$2.87:3.01::275:(288)$$

Therefore the unit defective charge of Coal Special No. 1 is 288 grams.

GAS AND DUST GALLERY NO. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Mar. 25.....	315	7.95	No ignition.	Mar. 26.....	315		No ignition.
Do.....	315	7.98	Do.	Do.....	315		Do.
Do.....	315	7.96	Do.	Do.....	315		Do.
Do.....	315	8.02	Do.	Do.....	315		Do.
Do.....	315	8.15	Do.	Do.....	315		Do.
Do.....	315	8.02	Do.	Do.....	315		Do.
Do.....	315	8.07	Do.	Do.....	315		Do.
Do.....	315	8.28	Do.	Do.....	315		Do.
Do.....	315	8.22	Do.	Do.....	315		Do.
Do.....	315	8.05	Do.	Do.....	315		Do.
TEST 2.				TEST 4.			
Mar. 25.....	315	3.90	No ignition.	Mar. 24.....	a 680	4.12	No ignition.
Do.....	315	3.81	Do.	Do.....	a 680	4.18	Do.
Do.....	315	3.97	Do.	Do.....	a 680	4.13	Do.
Do.....	315	4.07	Do.	Do.....	a 680	4.13	Do.
Do.....	315	4.14	Do.	Do.....	a 680	4.09	Do.
Mar. 26.....	315	4.15	Do.	TEST 5.			
Do.....	315	4.84	Do.	Apr. 8.....	a 680	2.02	No ignition.
Do.....	315	3.97	Do.				
Do.....	315	3.85	Do.				
Apr. 8.....	315	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.
Electric detonator No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Apr. 23.....	11. 90	43	3,613
Apr. 24.....	12. 00	43	3,583

Average rate of detonation 3,598 meters (11,800 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Apr. 27.....	18. 50	23. 37	8. 00	0. 400
Apr. 28.....	19. 00	24. 00	7. 25	. 362
Do.....	17. 75	22. 42	7. 25	. 362

Average height of flame, 23.26 inches.

Average duration of flame, 0.375 milliseconds.

IMPACT TESTS.

Date, May 7, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	No explosion.	15	1	Explosion.
20	1	Explosion.	14	3	No explosion.
19	1	Do.	14	1	Explosion.
18	1	Do.	13	1	No explosion.
18	1	No explosion.	13	1	Explosion.
17	1	Explosion.	12	5	No explosion.
16	1	Do.			

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
May 8.....	6	Exploded.	May 8.....	11	Did not explode.
Do.....	8	Do.	May 10.....	11	Do.
Do.....	10	Do.	May 18.....	11	Do.
Do.....	12	Did not explode.			

The minimum distance at which no explosion occurs is established at 11 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
May 7.....	200	1.21	28.85	72.12	A	72.37
Do.....	200	1.21	29.25	73.12	A	
Do.....	200	1.21	28.75	71.88	A	
Do.....	200	1.21	26.75	66.88	B	
Do.....	200	1.21	26.50	66.25	B	66.67
Do.....	200	1.21	26.75	66.88	B	
Do.....	200	1.21	25.75	64.38	C	
Do.....	200	1.21	25.75	64.38	C	
May 8.....	200	1.21	25.75	64.38	C	63.75
Do.....	200	1.21	25.00	62.50	C	

$P=1.911A+0.5B-1.411C=81.68$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.14$. $W=200$ grams.

$M=\frac{VPS}{W}=69.84$ kilograms per square centimeter (99,329 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 19, 1909.

	Grams.
Solid.....	65.8
Liquid (water).....	13.8
Gaseous.....	102.4

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Apr. 18.....	85.18	0.843	806.8
Do.....	84.98	.858	819.6
Apr. 20.....	82.58	.847	788.7

Average large calories per kilogram of explosive, 805.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Apr. 8.....	64.0	48.5	15.5
Do.....	64.0	48.0	16.0
Do.....	64.0	48.0	16.0

Average compression, 15.8 millimeters (0.62 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>°C.</i>
Apr. 10.....	62	216	154	15
Do.....	62	212	150	15
Do.....	62	218	156	15

Average expansion of bore hole, 153 cubic centimeters (9.33 cubic inches).

COAL SPECIAL NO. 2.

Explosive, Coal Special No. 2.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 209 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 1.12.

Color of explosive, café-au-lait.

Consistency, mixed granular and fibrous, moderately cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date: March 27, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge in grams, 310, 310, 310.

Swing, in inches, 3.07, 3.05, 3.09.

Average swing, in inches, 3.07.

$$3.07:3.01::310:(304).$$

Therefore the unit defective charge of Coal Special No. 2 is 304 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Mar. 27.....	304	8.44	No ignition.	Apr. 7.....	304	.....	No ignition.
Do.....	304	8.42	Do.	Do.....	304	.....	Do.
Mar. 28.....	304	7.76	Do.	Do.....	304	.....	Do.
Do.....	304	7.66	Do.	Do.....	304	.....	Do.
Do.....	304	8.09	Do.	Do.....	304	.....	Do.
Do.....	304	8.07	Do.	Do.....	304	.....	Do.
Do.....	304	7.92	Do.	Do.....	304	.....	Do.
Do.....	304	7.92	Do.	Do.....	304	.....	Do.
Do.....	304	8.61	Do.	Do.....	304	.....	Do.
Do.....	304	8.59	Do.	Do.....	304	.....	Do.
TEST 2.				TEST 4.			
Apr. 6.....	304	4.06	No ignition.	Mar. 25.....	a 680	3.94	No ignition.
Do.....	304	4.06	Do.	Do.....	a 680	3.97	Do.
Do.....	304	3.98	Do.	Do.....	a 680	3.89	Do.
Do.....	304	4.15	Do.	Do.....	a 680	4.01	Do.
Do.....	304	4.57	Do.	Do.....	a 680	3.94	Do.
Do.....	304	4.15	Do.	TEST 5.			
Do.....	304	4.11	Do.				
Do.....	304	4.19	Do.	Mar. 25.....	a 680	2.10	No ignition.
Do.....	304	4.19	Do.				
Do.....	304	4.06	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Apr. 26.....	13.90	43	3,094
Do.....	13.64	43	3,152

Average rate of detonation, 3,123 meters (10,240 feet per second).

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Millisecond.</i>
Apr. 28.....	19.0	24.00	9.25	0.462
June 11.....	19.0	24.00	10.25	.512
Do.....	20.0	25.26	9.50	.475

Average height of flame, 24.42 inches.

Average duration of flame, 0.483 millisecond.

IMPACT TESTS.

Date, May 7, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	Explosion.	13	1	Explosion.
14	1	Do.	12	5	No explosion.

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
May 24.....	10	Exploded.	May 27.....	14	Did not explode.
May 27.....	12	Did not explode.	May 28.....	14	Exploded.
Do.....	11	Do.	Do.....	15	Do.
Do.....	11	Exploded.	Do.....	16	Did not explode.
Do.....	12	Do.	Do.....	16	Do.
Do.....	13	Do.	Do.....	16	Do.

The minimum distance at which no explosion occurs is established at 16 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 centimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
May 10.....	200	1.18	27.75	69.38	A	68.33
Do.....	200	1.18	27.50	68.75	A	
Do.....	200	1.18	26.75	66.88	A	
May 8.....	200	1.18	25.50	63.75	B	63.33
Do.....	200	1.18	25.25	63.12	B	
Do.....	200	1.18	25.25	63.12	B	
Do.....	200	1.18	24.00	60.00	C	60.66
May 10.....	200	1.18	24.80	62.00	C	
Do.....	200	1.18	24.00	60.00	C	

$P=1.911A+0.5B-1.411C=76.65$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=1.12$. $W=200$ grams.
 $M=\frac{VPS}{W}=6,439$ kilograms per square centimeter (91,578 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 23, 1909.

	Grams.
Solid.....	74.2
Liquor (water).....	13.8
Gaseous.....	104.4

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Apr. 19.....	84.13	0.809	765.5
Do.....	83.95	.818	772.6
Apr. 20.....	82.83	.835	779.5

Average large calories per kilogram of explosive, 772.5.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Apr. 8.....	64.0	50.0	14.0
Do.....	64.0	49.7	14.3
Apr. 12.....	64.0	50.0	14.0

Average compression, 14.1 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>
Apr. 10.....	62	215	153	15
Do.....	62	208	146	15
Do.....	62	204	142	15

Average expansion of bore hole, 147 cubic centimeters (8.97 cubic inches).

COALITE NO. 1.

Explosive, Coalite No. 1.

Class, nitroglycerin.

Manufactured by Potts Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 225 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.32.

Color of explosive, light ocher.

Consistency, granular.

Unit defective charge as determined by the ballistic pendulum:

Date, March 1, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 290, 290, 290.

Swing, in inches, 3.00, 2.93, 2.91.

Average swing, in inches, 2.95.

$$2.95:3.01::290:(296).$$

Therefore the unit defective charge of Coalite No. 1 is 296 grams.

GAS AND DUST GALLERY NO. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Mar. 8.....	296	8.04	No ignition.	Mar. 10.....	296		No ignition.
Do.....	296	7.97	Do.	Do.....	296		Do.
Do.....	296	7.97	Do.	Do.....	296		Do.
Do.....	296	7.77	Do.	Do.....	296		Do.
Do.....	296	7.98	Do.	Do.....	296		Do.
Do.....	296	8.46	Do.	Do.....	296		Do.
Mar. 9.....	296	7.84	Do.	Mar. 11.....	296		Do.
Do.....	296	7.87	Do.	Do.....	296		Do.
Do.....	296	7.96	Do.	Do.....	296		Do.
Do.....	296	7.94	Do.	Do.....	296		Do.
TEST 2.				TEST 4.			
Mar. 9.....	296	3.91	No ignition.	Mar. 15.....	a 680	3.97	No ignition.
Do.....	296	3.87	Do.	Do.....	a 680	4.02	Do.
Do.....	296	4.09	Do.	Do.....	a 680	3.97	Do.
Do.....	296	3.95	Do.	Mar. 16.....	a 680	3.92	Do.
Do.....	296	4.20	Do.	Do.....	a 680	3.92	Do.
Do.....	296	4.12	Do.	TEST 5.			
Do.....	296	4.14	Do.	Mar. 16.....	a 680	2.08	No ignition.
Do.....	296	4.01	Do.				
Do.....	296	4.03	Do.				
Do.....	296	4.10	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Apr. 5.....	18. 16	43	2, 368
Apr. 6.....	17. 42	43	2, 468

Average rate of detonation, 2,418 meters (7,930 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Millisecond.</i>
Apr. 9.....	15. 00	18. 95	6. 50	0. 325
Do.....	13. 50	17. 05	5. 80	. 290
Apr. 13.....	13. 80	17. 43	4. 80	. 240

Average height of flame, 17.81 inches.
Average duration of flame, 0.285 millisecond.

IMPACT TESTS.

Date, March 18, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	Explosion.	12	1	Explosion.
12	1	No explosion.	11	1	Do.
14	4	Do.	10	3	No explosion.
14	1	Explosion.	10	1	Explosion.
13	1	Do.	9	5	No explosion.
12	1	No explosion.			

The maximum height at which no explosion occurs is established at 9 centimeters (3.54 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 225 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Apr. 2.....	6	Exploded.	Apr. 3.....	8	Did not explode.
Do.....	8	Did not explode.	Do.....	8	Do.
Do.....	7	Exploded.			

The minimum distance at which no explosion occurs is established at 8 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Apr. 6.....	200	1.42	26.25	65.62	A	67.08
Do.....	200	1.37	26.50	66.25	A	
Do.....	200	1.42	27.75	69.38	A	
Apr. 3.....	200	1.58	24.50	61.25	B	61.88
Apr. 7.....	200	1.38	25.25	63.12	B	
Do.....	200	1.49	24.50	61.25	B	
Apr. 5.....	200	1.42	24.00	60.00	C	59.58
Do.....	200	1.42	23.25	58.12	C	
Do.....	200	1.42	24.25	60.62	C	

$P=1.911A+0.5B-1.411C=75.06$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=1.32$. $W=200$ grams.
 $N=\frac{VPS}{W}=7,431$ kilograms per square centimeter (105,687 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 29, 1909.	Grams.
Solid.....	62.3
Liquid (water).....	12.0
Gaseous.....	105.3

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Height of water.	Rise in temperature.	Development per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Apr. 5.....	83.53	0.764	717.8
Do.....	83.35	.749	702.2
Apr. 6.....	83.68	.778	732.3

Average large calories per kilogram of the explosive, 717.4.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Mar. 26.....	64.0	51.5	12.5
Do.....	64.0	52.0	12.0
Do.....	64.0	52.0	12.0

Average compression, 12.2 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
	Cubic centi- meters.	Cubic centi- meters.	Cubic centi- meters.	° C.
Mar. 10.....	62	221	159	17
Do.....	62	218	156	17
Do.....	62	218	156	17

Average expansion of bore hole, 157 cubic centimeters (9.58 cubic inches).

COALITE NO. 2 D.

Explosive: Coalite No. 2 D.

Class: Nitroglycerin.

Manufactured by Potts Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 220 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.27.

Color of explosive, buff.

Consistency, granular, moderately cohesive.

Unit defective charge as determined by the ballistic pendulum.

Date, March 1, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 315, 315, 315.

Swing, in inches, 3.08, 3.04, 3.05.

Average swing, in inches, 3.06.

$$3.06 : 3.01 :: 315 : (310).$$

Therefore the unit defective charge of Coalite No. 2 D is 310 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
Mar. 9.....	Grams. 310	Per cent. 7.91	No ignition.	Mar. 11.....	Grams. 310	Per cent.	No ignition.
Do.....	310	7.79	Do.	Do.....	310	.....	Do.
Do.....	310	7.84	Do.	Do.....	310	.....	Do.
Do.....	310	8.05	Do.	Do.....	310	.....	Do.
Do.....	310	7.85	Do.	Do.....	310	.....	Do.
Do.....	310	7.79	Do.	Do.....	310	.....	Do.
Do.....	310	8.08	Do.	Do.....	310	.....	Do.
Do.....	310	8.08	Do.	Do.....	310	.....	Do.
Do.....	310	7.84	Do.	Do.....	310	.....	Do.
Do.....	310	8.04	Do.	Do.....	310	.....	Do.
TEST 2.				TEST 4.			
Mar. 9.....	310	3.97	No ignition.	Mar. 13.....	a 680	4.03	No ignition.
Do.....	310	4.15	Do.	Do.....	a 680	4.03	Do.
Do.....	310	4.13	Do.	Do.....	a 680	4.12	Do.
Do.....	310	4.01	Do.	Mar. 14.....	a 680	3.98	Do.
Do.....	310	4.06	Do.	Mar. 15.....	a 680	3.94	Do.
Do.....	310	4.06	Do.	TEST 5.			
Mar. 10.....	310	4.06	Do.	Mar. 16.....	a 680	2.00	No ignition.
Do.....	310	4.03	Do.				
Do.....	310	4.15	Do.				
Do.....	310	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Apr. 6.....	16.83	43	2,555
Apr. 7.....	16.62	43	2,587

Average rate of detonation, 2,571 meters (8,430 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Apr. 9.....	16.50	20.84	7.00	0.350
Apr. 13.....	16.00	20.21	6.50	.325
Do.....	16.00	20.21	7.00	.350

Average height of flame, 20.42 inches.

Average duration of flame, 0.342 milliseconds.

IMPACT TESTS.

Date, March 8, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	Explosion.	13	1	Explosion.
15	1	No explosion.	12	1	No explosion.
18	1	Explosion.	12	1	Explosion.
17	1	Do.	11	1	Do.
16	1	Do.	10	1	No explosion.
15	1	Do.	10	1	Explosion.
14	2	No explosion.	9	5	No explosion.
14	1	Explosion.			

The maximum height at which no explosion occurs is established at 9 centimeters (3.54 inches).

EXPLOSION BY INFLUENCE TEST

Weight of each cartridge, 220 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Apr. 10.....	6	Did not explode.	Apr. 12.....	3	Exploded.
Apr. 12.....	4	Do.	Do.....	4	Did not explode.
Do.....	2	Exploded.	Do.....	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Apr. 10.....	200	1.24	25.75	64.38	A	65.84
Apr. 13.....	200	1.28	26.50	66.25	A	
Do.....	200	1.28	26.75	66.88	A	
Apr. 8.....	200	1.28	24.50	61.25	B	60.83
Do.....	200	1.28	24.50	61.25	B	
Do.....	200	1.28	24.00	60.00	B	
Apr. 9.....	200	1.28	24.00	60.00	C	58.54
Do.....	200	1.28	23.25	58.12	C	
Apr. 10.....	200	1.24	23.00	57.50	C	

$P=1.911A+0.5B-1.411C=73.64$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=1.27$. $W=200$ grams.
 $M=\frac{VPS}{W}=7,014$ kilograms per square centimeter (99,756 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 7, 1909.	Grams.
Solid.....	82.3
Liquid (water).....	11.4
Gaseous.....	85.5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Apr. 9.....	83.46	0.844	793.3
Do.....	83.28	.843	790.8
Apr. 10.....	84.48	.826	784.6

Average large calories per kilogram of the explosive, 789.6.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Mar. 26.....	64.0	52.0	12.0
Do.....	64.0	52.0	12.0
Do.....	64.0	52.7	11.3

Average compression, 11.8 millimeters (0.46 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	°C.
Mar. 10.....	62	212	150	17
Do.....	62	207	145	17
Do.....	62	206	144	17

Average expansion of bore hole, 146 cubic centimeters (8.91 cubic inches).

COLLIER POWDER NO. 2.

Explosive, Collier Powder No. 2.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 148 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.84.

Color of explosive, drab.

Consistency, dry, fibrous.

Unit defective charge as determined by the ballistic pendulum:

Date, April 5, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge, in grams, 280, 280, 280.

Swing, in inches, 2.65, 2.55, 2.65.

Average swing, in inches, 2.617.

$$2.617 : 2.80 :: 280 : (300).$$

Therefore the defective charge of Collier Powder No. 2 is 300 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
Apr. 9.....	Grams. 300	Per cent. 7.90	No ignition.	Apr. 9.....	Grams. 300	Per cent.	No ignition.
Do.....	300	7.88	Do.	Do.....	300	.....	Do.
Do.....	300	7.95	Do.	Do.....	300	.....	Do.
Do.....	300	8.11	Do.	Do.....	300	.....	Do.
Do.....	300	7.98	Do.	Do.....	300	.....	Do.
Do.....	300	7.88	Do.	Do.....	300	.....	Do.
Do.....	300	7.83	Do.	Do.....	300	.....	Do.
Do.....	300	8.06	Do.	Do.....	300	.....	Do.
Do.....	300	7.88	Do.	Do.....	300	.....	Do.
Do.....	300	7.83	Do.	Do.....	300	.....	Do.
TEST 2.				TEST 4.			
Apr. 8.....	300	3.94	No ignition.	Apr. 10.....	a 680	4.28	No ignition.
Do.....	300	3.94	Do.	Do.....	a 680	4.04	Do.
Do.....	300	4.04	Do.	Apr. 11.....	a 680	3.79	Do.
Do.....	300	4.04	Do.	Do.....	a 680	3.86	Do.
Do.....	300	4.03	Do.	Do.....	a 680	3.94	Do.
Do.....	300	4.11	Do.	TEST 5.			
Do.....	300	4.11	Do.	Apr. 22.....	a 680	2.10	No ignition.
Do.....	300	4.03	Do.				
Do.....	300	4.11	Do.				
Do.....	300	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
May 15.....	16.97	43	2,694
June 18.....	15.85	43	2,713

Average rate of detonation, 2,704 meters (8,870 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
May 22.....	15.75	19.89	6.50	0.325
Do.....	16.00	20.21	7.50	.375
Do.....	15.25	19.26	7.25	.362

Average height of flame, 19.79 inches.

Average duration of flame, 0.354 millisecond.

IMPACT TEST.

Date, June 3, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i> 15	1	Explosion.	<i>Centimeters.</i> 14	5	No explosion.

The maximum height at which no explosion occurs is established at 14 centimeters (5.51 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 149 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
June 7.....	6	Did not explode.	June 7.....	3	Exploded.
Do.....	4	Do.	June 8.....	4	Did not explode.
Do.....	2	Exploded.	Do.....	4	Do.
Do.....	3	Did not explode.			

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
May 28.....	200	0.93	26.50	66.25	A	67.92
Do.....	200	.91	28.00	70.00	A	
May 29.....	200	.93	27.00	67.50	A	
May 26.....	200	.86	24.50	61.25	B	61.46
Do.....	200	.86	24.75	61.88	B	
May 27.....	200	.86	24.50	61.25	B	
Do.....	200	.86	23.50	58.75	C	58.12
June 1.....	200	.93	22.75	56.88	C	
Do.....	200	.93	23.50	58.75	C	

$P=1.911 A+0.5 B-1.411 C=78.52$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=0.84$. $W=200$ grams.

$M=\frac{VPS}{W}=4,947$ kilograms per square centimeter (70,358 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 14, 1909.

	Grams.
Solid.....	60.3
Liquid (water).....	14.7
Gaseous.....	114.6

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
June 9.....	82.27	0.765	709.1
June 10.....	82.27	.740	685.7
Do.....	82.27	.751	696.0

Average large calories per kilogram of explosive, 696.9.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height before explosion.	Height after explosion.	Compression.
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Apr. 15.....	64.0	51.5	12.5
Apr. 21.....	64.0	51.3	12.7
Do.....	63.8	51.7	12.1

Average compression, 12.4 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole before shot.	Volume of bore hole after shot.	Expansion of bore hole.	Tempera- ture of block.
	<i>Cubic centi- meters.</i>	<i>Cubic centi- meters.</i>	<i>Cubic centi- meters.</i>	<i>° C.</i>
Apr. 10.....	62	222	160	15
Do.....	62	212	150	15
Do.....	62	205	143	15

Average expansion of bore hole, 151 cubic centimeters (9.21 cubic inches).

COLLIER POWDER NO. 4.

Explosive: Collier Powder No. 4.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 150 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.88.

Color of explosive, light buff.

Consistency, dry, fibrous.

Unit defective charge as determined by the ballistic pendulum:

Date, April 7, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge, in grams, 280, 280, 280.

Swing, in inches, 2.94, 2.78, 2.80.

Average swing, in inches, 2.84.

$$2.84 : 2.80 :: 280 :: (276).$$

Therefore the unit defective charge of Collier Powder No. 4 is 276 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Apr. 8.....	276	8.24	No ignition.	Apr. 9.....	276	.....	No ignition.
Do.....	276	8.14	Do.	Do.....	276	.....	Do.
Do.....	276	8.22	Do.	Do.....	276	.....	Do.
Do.....	276	8.11	Do.	Do.....	276	.....	Do.
Do.....	276	8.09	Do.	Do.....	276	.....	Do.
Apr. 9.....	276	8.06	Do.	Do.....	276	.....	Do.
Do.....	276	8.06	Do.	Do.....	276	.....	Do.
Do.....	276	7.83	Do.	Apr. 10.....	276	.....	Do.
Do.....	276	7.90	Do.	Do.....	276	.....	Do.
Do.....	276	7.81	Do.	Do.....	276	.....	Do.
TEST 2.				TEST 4.			
Apr. 8.....	276	4.03	No ignition.	Apr. 10.....	α 680	4.03	No ignition.
Do.....	276	4.28	Do.	Apr. 11.....	α 680	4.03	Do.
Do.....	276	4.19	Do.	Do.....	α 680	4.03	Do.
Do.....	276	4.19	Do.	Apr. 21.....	α 680	4.10	Do.
Do.....	276	4.11	Do.	Do.....	α 680	4.19	Do.
Do.....	276	4.03	Do.				
Do.....	276	4.19	Do.	TEST 5.			
Do.....	276	4.19	Do.	Apr. 21.....	α 680	2.09	No ignition.
Do.....	276	4.03	Do.				
Do.....	276	4.11	Do.				

α 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
June 18	12.39	43	3,471
June 24	13.15	43	3,270

Average rate of detonation, 3,370 meters (11,050 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
May 28.....	20.50	25.89	10.25	0.512
Do.....	20.50	25.89	9.75	.488
Do.....	21.25	26.84	9.25	.462

Average height of flame, 26.21 inches.

Average duration of flame, 0.487 millisecond.

IMPACT TESTS.

Date, June 3, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	No explosion.	18	1	Explosion.
20	1	Do.	17	1	Do.
25	1	Explosion.	16	1	Do.
24	1	Do.	15	1	No explosion.
23	1	Do.	15	1	Explosion.
22	1	Do.	14	1	Do.
21	1	Do.	13	1	No explosion.
20	1	Do.	13	1	Explosion.
19	1	Do.	12	5	No explosion.

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 150 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
June 8.....	4	Exploded.	June 8.....	5	Exploded.
Do.....	6	Did not explode.	June 9.....	6	Did not explode.
Do.....	5	Do.	Do.....	6	Do.

The minimum distance at which no explosion occurs is established at 6 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
June 2.....	200	0.90	27.50	68.75	A	69.58
Do.....	200	.90	28.00	70.00	A	
Do.....	200	.90	28.00	70.00	A	
June 3.....	200	.90	26.00	65.00	B	63.54
Do.....	200	.90	24.75	61.88	B	
Do.....	200	.90	25.50	63.75	B	
Do.....	200	.90	24.00	60.00	C	61.25
June 10.....	200	.90	24.00	60.00	C	
Do.....	200	.90	25.50	63.75	C	

$P=1.911A+0.5B-1.411C=78.31$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=0.88$. $W=200$ grams.
 $M=\frac{VPS}{W}=5,168$ kilograms per square centimeter (73,501 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 17, 1909.

	Grams.
Solid.....	65.3
Liquid (water).....	8.2
Gaseous.....	110.6

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
June 10.....	83.27	0.815	764.2
June 11.....	83.27	.826	774.6
Do.....	83.27	.797	747.1

Average large calories per kilogram of explosive, 762.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Apr. 15.....	64.0	50.0	14.0
Do.....	64.0	50.3	13.7
Apr. 21.....	63.8	49.5	14.3

Average compression, 14.0 millimeters (0.55 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>°C.</i>
Apr. 10.....	62	240	178	15
Do.....	62	244	182	15
Do.....	62	260	198	15

Average expansion of bore hole, 186 cubic centimeters (11.35 cubic inches).

COLLIER POWDER NO. 5.

Explosive, Collier Powder No. 5.

Class, Ammonium nitrate, containing nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 158.5 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.97.

Color of explosive, fawn.

Consistency, granular, cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, April 5, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge in grams, 235, 235, 235.

Swing, in inches, 2.910, 2.725, 2.600.

Average swing in inches, 2.745.

 $2.745:2.80::235:(240)$.

Therefore the unit defective charge of Collier Powder No. 5 is 240 grams.

GAS AND DUST GALLERY NO. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
Apr. 9.....	<i>Grams.</i> 240	<i>Per cent.</i> 8.09	No ignition.	Apr. 9.....	<i>Grams.</i> 240	<i>Per cent.</i>	No ignition.
Do.....	240	8.09	Do.	Apr. 10.....	240	.....	Do.
Do.....	240	7.97	Do.	Do.....	240	.....	Do.
Do.....	240	7.97	Do.	Do.....	240	.....	Do.
Do.....	240	7.98	Do.	Do.....	240	.....	Do.
Do.....	240	8.01	Do.	Do.....	240	.....	Do.
Do.....	240	7.94	Do.	Do.....	240	.....	Do.
Do.....	240	8.26	Do.	Do.....	240	.....	Do.
Do.....	240	7.97	Do.	Do.....	240	.....	Do.
Do.....	240	8.11	Do.	Do.....	240	.....	Do.
TEST 2.				TEST 4.			
Apr. 8.....	240	4.19	No ignition.	Apr. 10.....	α 680	4.11	No ignition.
Do.....	240	4.21	Do.	Apr. 11.....	α 680	3.96	Do.
Do.....	240	4.19	Do.	Apr. 22.....	α 680	3.96	Do.
Do.....	240	4.36	Do.	Do.....	α 680	4.20	Do.
Do.....	240	4.22	Do.	Do.....	α 680	4.05	Do.
Do.....	240	3.96	Do.	TEST 5.			
Do.....	240	4.11	Do.	Apr. 22.....	α 680	2.02	No ignition.
Do.....	240	4.11	Do.				
Do.....	240	4.03	Do.				
Do.....	240	4.19	Do.				

α 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
June 24.....	17.20	43	2,500
June 25.....	16.88	43	2,547

Average rate of detonation 2,524 meters (8,280 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
May 13.....	15.25	19.26	7.50	0.375
Do.....	15.50	19.58	7.00	.350
May 22.....	16.00	20.21	6.00	.300

Average height of flame, 19.68 inches.

Average duration of flame, 0.342 milliseconds.

IMPACT TESTS.

Date, June 25, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	30	1	Explosion.
25	1	Do.	25	1	No explosion.
40	1	Explosion.	26	1	Explosion.
35	1	Do.	25	1	No explosion.
30	1	No explosion.	25	1	Explosion.
34	1	Do.	24	1	Do.
34	1	Explosion.	23	3	No explosion.
33	1	Do.	23	1	Explosion.
32	1	Do.	22	5	No explosion.
31	1	Do.			

The maximum height at which no explosion occurs is established at 22 centimeters (8.66 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 159 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
June 10.....	4	Did not explode.	June 10.....	2	Did not explode.
Do.....	2	Do.	Do.....	2	Do.
Do.....	1	Exploded.			

The minimum distance at which no explosion occurs is established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
June 3.....	200	1.04	36.50	91.25	A	93.12
Do.....	200	1.04	37.50	93.75	A	
June 4.....	200	1.04	37.75	94.38	A	
June 11.....	200	1.04	32.00	80.00	B	73.12
June 12.....	200	1.04	27.80	69.50	B	
Do.....	200	1.04	26.50	66.25	B	
June 14.....	200	1.02	34.20	85.50	B	73.12
Do.....	200	1.02	28.50	71.25	B	
Do.....	200	1.02	28.50	71.25	B	
Do.....	200	1.04	27.25	68.12	B	67.03
June 12.....	200	1.04	27.00	67.50	C	
Do.....	200	1.04	25.50	63.75	C	
Do.....	200	1.04	26.00	65.00	C	67.03
June 14.....	200	1.04	28.75	71.83	C	

$P=1.911A+0.5B-1.411C=119.93$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=0.97$. $W=200$ grams.

$M=\frac{VPS}{W}=8,725$ kilograms per square centimeter (124,090 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 20, 1909.

	<i>Grams.</i>
Solid.....	17.8
Liquid (water).....	71.5
Gaseous.....	96.2

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
June 11.....	83.15	0.949	890.1
June 25.....	82.13	.898	832.6

Average large calories per kilogram of explosive, 861.4.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Apr. 15.....	64.0	52.0	12.0
Do.....	64.0	51.3	12.7
Do.....	64.0	51.3	12.7

Average compression, 12.5 millimeters (0.49 cubic inches).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>° C.</i>
Apr. 10.....	62	262	200	15
Do.....	62	270	208	15
Apr. 12.....	62	278	216	15

Average expansion of bore hole, 208 cubic centimeters (12.69 cubic inches).

MASURITE M. L. F.

Explosive, Masurite M. L. F.

Class, ammonium nitrate.

Manufactured by Masurite Explosives Co.

Physical examination:

Packed loose in 5-pound waterproof canisters.

Color of explosive, iron gray.

Apparent specific gravity of prepared cartridge by sand, 0.97.

Consistency, granular dry powder.

Unit defective charge as determined by the ballistic pendulum:

Date, April 30, 1909.

Unit swing used on this date: 2.77 inches.

Weight of charge, in grams: 266, 266, 266.

Swing, in inches: 2.68, 2.56, 2.67.

Average swing, in inches: 2.64.

$$2.64 : 2.77 :: 266 : (279).$$

Therefore the unit defective charge of Masurite M. L. F. is 279 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.	<i>Grams.</i>	<i>Per cent.</i>		TEST 3.	<i>Grams.</i>	<i>Per cent.</i>	
May 3.....	279	7.96	No ignition.	May 5.....	279	.....	No ignition.
Do.....	279	8.07	Do.	Do.....	279	.....	Do.
Do.....	279	8.16	Do.	Do.....	279	.....	Do.
Do.....	279	8.66	Do.	Do.....	279	.....	Do.
Do.....	279	8.10	Do.	Do.....	279	.....	Do.
Do.....	279	8.25	Do.	Do.....	279	.....	Do.
Do.....	279	8.25	Do.	Do.....	279	.....	Do.
May 4.....	279	8.22	Do.	Do.....	279	.....	Do.
Do.....	279	8.14	Do.	Do.....	279	.....	Do.
Do.....	279	8.20	Do.	Do.....	279	.....	Do.
TEST 2.				TEST 4.			
May 4.....	279	4.14	No ignition.	May 1.....	a 680	4.05	No ignition.
Do.....	279	4.23	Do.	Do.....	a 680	3.98	Do.
Do.....	279	4.24	Do.	Do.....	a 680	4.20	Do.
Do.....	279	4.22	Do.	Do.....	a 680	3.94	Do.
Do.....	279	4.24	Do.	Do.....	a 680	4.14	Do.
Do.....	279	4.17	Do.	TEST 5.			
Do.....	279	4.06	Do.	May 1.....	a 680	2.10	No ignition.
Do.....	279	4.12	Do.				
Do.....	279	4.15	Do.				
Do.....	279	4.26	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Aug. 14.....	13.00	45	3.462
Aug. 17.....	12.69	43	3.413

Average rate of detonation, 3,488 meters (11,280 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
May 27.....	20.50	25.89	10.00	0.500
Do.....	20.00	25.26	9.00	.450
Do.....	20.50	25.89	10.00	.500

Average height of flame, 25.68 inches.

Average duration of flame, 0.483 milliseconds.

IMPACT TESTS.

Date, May 5, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
60	1	Explosion.	15	1	No explosion.
50	1	Do.	19	2	Explosion.
40	1	Do.	18	2	No explosion.
30	1	Do.	18	1	Explosion.
20	1	Do.	17	5	No explosion.

The maximum height at which no explosion occurs is established at 17 centimeters (6.69 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 159 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Aug. 19.....	2	Did not explode.	Aug. 19.....	2	Did not explode.
Do.....	1	Exploded.	Do.	2	Do.

The minimum distance at which no explosion occurs is established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

► Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
June 21.....	200	1.05	36.75	91.88	A	89.45
Do.....	200	1.05	35.12	87.80	A	
Do.....	200	1.05	35.25	88.12	A	
June 22.....	200	1.05	36.00	90.00	A	82.82
June 21.....	200	1.05	35.50	88.75	B	
Do.....	200	1.05	32.38	80.95	B	
June 22.....	200	1.05	31.50	78.75	B	79.38
Do.....	200	1.05	31.75	79.38	C	
Do.....	200	1.05	32.25	80.62	C	
June 23.....	200	1.05	31.25	78.12	C	

P=1.911A+0.5 B-1.411 C=100.34 kilograms per square centimeter.

V=15.000 cubic centimeters. S=0.97. W=200 grams.

$M=\frac{VPS}{W}=7,300$ kilograms per square centimeter (103,824 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 21, 1909.

	Grams.
Solid.....	27.5
Liquid (water).....	75.5
Gaseous.....	89.8

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
June 25.....	82.13	1.055	979.7
Do.....	82.13	1.068	991.9
Do.....	82.13	1.084	1006.9

Average large calories per kilogram of explosive, 992.8.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
May 12.....	64.0	49.8	14.2
Do.....	64.0	49.8	14.2
Do.....	64.0	50.0	14.0

Average compression, 14.1 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
June 29.....	62	290	228	29
Do.....	62	280	218	29

Average expansion of bore hole, 223 cubic centimeters (13.60 cubic inches).

METEOR AXXO.

Explosive, Meteor AXXO.

Class, hydrated, containing nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 356 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 1.54.

Color of explosive, dove-colored mass with glistening black particles.

Consistency, cohesive.

Unit defective charge as determined by the ballistic pendulum:

Date, February 13, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 440, 440, 440.

Swing, in inches, 2.99, 3.00, 3.07.

Average swing, in inches, 3.05.

3.05: 3.01: 440: (434).

Therefore the unit defective charge of Meteor AXXO is 434 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Feb. 16.....	434	8.02	No ignition.	Feb. 19.....	434	.....	No ignition.
Do.....	434	7.88	Do.	Do.....	434	.....	Do.
Do.....	434	7.90	Do.	Do.....	434	.....	Do.
Do.....	434	7.85	Do.	Do.....	434	.....	Do.
Do.....	434	7.77	Do.	Do.....	434	.....	Do.
Do.....	434	7.95	Do.	Do.....	434	.....	Do.
Do.....	434	7.89	Do.	Do.....	434	.....	Do.
Do.....	434	7.80	Do.	Do.....	434	.....	Do.
Do.....	434	8.02	Do.	Do.....	434	.....	Do.
Do.....	434	7.88	Do.	Do.....	434	.....	Do.
TEST 2.				TEST 4.			
Feb. 17.....	434	4.04	No ignition.	Feb. 21.....	a 680	3.83	No ignition.
Do.....	434	3.97	Do.	Do.....	a 680	3.79	Do.
Do.....	434	3.93	Do.	Do.....	a 680	3.74	Do.
Do.....	434	4.02	Do.	Feb. 23.....	a 680	3.85	Do.
Do.....	434	3.74	Do.	Do.....	a 680	4.03	Do.
Do.....	434	3.95	Do.	TEST 5.			
Do.....	434	3.96	Do.				
Do.....	434	4.01	Do.	Feb. 24.....	a 680	2.04	No ignition.
Do.....	434	4.04	Do.				
Do.....	434	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Aug. 13.....	17.03	43	2,525
Do.....	16.53	43	2,601

Average rate of detonation 2,563 meters (8,410 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration. distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Mar. 12.....	14.00	17.68	6.62	0.331
Do.....	13.75	17.37	6.75	.338
Do.....	14.38	18.16	6.62	.331

Average height of flame, 17.74 inches.

Average duration of flame, 0.333 milliseconds.

IMPACT TESTS.

Date, February 19, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
15	1	Explosion.	10	2	No explosion.
14	1	Do.	10	1	Explosion.
13	1	Do.	9	2	No explosion.
12	1	Do.	9	1	Explosion.
11	1	Do.	8	5	No explosion

The maximum height at which no explosion occurs is established at 8 centimeters (3.15 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 249 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 23.....	6	Did not explode.	Mar. 24.....	3	Exploded.
Mar. 24.....	5	Do.	Mar. 26.....	4	Did not explode.
Do.....	4	Do.	Do.....	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Feb. 15.....	100	1.47	13.50	24.10	A	23.63
Do.....	100	1.47	13.20	23.57	A	
Feb. 17.....	100	1.47	13.00	23.21	A	
Mar. 26.....	100	1.57	11.00	19.64	B	20.09
Do.....	100	1.57	11.50	20.54	B	
Do.....	100	1.57	11.25	20.09	B	
Mar. 27.....	100	1.57	11.25	20.09	C	19.17
Do.....	100	1.57	10.45	18.66	C	
Do.....	100	1.57	10.50	18.75	C	

$P=1.911A+0.5B-1.411C=28.56$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.54$. $W=100$ grams.

$M=\frac{VPS}{W}=6,597$ kilograms per square centimeter (93,825 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 24, 1909.

	<i>Grams.</i>
Solid.....	56.0
Liquid (water).....	33.0
Gaseous.....	86.1

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Mar. 26.....	81.25	0.647	591.8
Do.....	81.49	.674	618.5
Mar. 27.....	83.48	.663	621.4

Average large calories per kilogram of explosive, 610.6.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 16.....	64.0	54.8	9.2
Do.....	64.0	54.5	9.5
Do.....	64.0	55.0	9.0

Average compression, 9.2 millimeters (0.36 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	° C.
Oct. 16.....	62	190	128	15
Do.....	62	195	133	15
Do.....	62	194	132	15

Average expansion of bore hole, 131 cubic centimeters (7.99 cubic inches).

MONOBEL NO. 1.

Explosive, Monobel No. 1.

Class, ammonium nitrate, containing nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, $1\frac{1}{2}$ inches.

Length of cartridge, 8 inches.

Average weight, 220 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 0.97.

Color of explosive, ocher.

Consistency, rather dry, fibrous powder.

Unit defective charge as determined by the ballistic pendulum:

Date, February 2, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 225, 225, 225.

Swing, in inches, 3.22, 3.11, 3.09.

Average swing, in inches, 3.14.

$$3.14 : 3.01 :: 225 : (216).$$

Therefore the unit defective charge of Monobel No. 1 is 216 grams.

GAS AND DUST GALLERY NO. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	<i>Grams.</i>	<i>Per cent.</i>			<i>Grams.</i>	<i>Per cent.</i>	
Feb. 8.....	216	8.43	No ignition.	Feb. 4.....	216		No ignition.
Do.....	216	7.96	Do.	Do.....	216		Do.
Do.....	216	7.84	Do.	Do.....	216		Do.
Do.....	216	8.33	Do.	Do.....	216		Do.
Do.....	216	8.04	Do.	Do.....	216		Do.
Do.....	216	7.91	Do.	Do.....	216		Do.
Do.....	216	7.89	Do.	Do.....	216		Do.
Do.....	216	8.01	Do.	Do.....	216		Do.
Do.....	216	8.10	Do.	Feb. 5.....	216		Do.
Feb. 19.....	216	8.24	Do.	Do.....	216		Do.
TEST 2.				TEST 4.			
Feb. 4.....	216	4.15	No ignition.	Mar. 2.....	a 680	3.99	No ignition.
Do.....	216	4.13	Do.	Do.....	a 680	4.05	Do.
Do.....	216	3.85	Do.	Do.....	a 680	4.05	Do.
Do.....	216	3.98	Do.	Mar. 5.....	a 680	4.02	Do.
Do.....	216	4.00	Do.	Do.....	a 680	4.02	Do.
Do.....	216	4.04	Do.	TEST 5.			
Do.....	216	3.88	Do.				
Do.....	216	4.09	Do.				
Do.....	216	4.02	Do.	Feb. 12.....	a 680	2.01	No ignition.
Do.....	216	3.91	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, $1\frac{1}{4}$ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 10.....	12.08	43	3,560
Mar. 11.....	12.02	43	3,577

Average rate of detonation 3,568 meters (11,700 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Mar. 11.....	17.12	21.63	5.25	0.262
Do.....	15.75	19.89	5.00	.250
Do.....	17.62	22.26	5.25	.262

Average height of flame, 21.26 inches.

Average duration of flame, 0.258 milliseconds.

IMPACT TESTS.

Date, February 2, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
20	1	No explosion.	27	1	Explosion.
30	1	Explosion.	26	1	Do.
25	1	No explosion.	25	3	No explosion.
27	1	Do.	25	1	Explosion.
23	1	Explosion.	24	5	No explosion.

The maximum height at which no explosion occurs is established at 24 centimeters (9.45 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 175 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Mar. 13.....	8	Did not explode.	Mar. 15.....	2	Exploded.
Do.....	6	Do.	Do.....	3	Did not explode.
Do.....	4	Do.	Do.....	3	Explosion.
Do.....	2	Do.	Do.....	4	Did not explode.
Do.....	1	Exploded.	Do.....	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 centimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Mar. 13.....	100	0.93	20.63	51.56	A	50.52
Do.....	100	.93	19.50	48.75	A	
Do.....	100	.93	20.50	51.25	A	
Mar. 11.....	100	.93	18.75	46.88	B	46.67
Do.....	100	.93	18.75	46.88	B	
Do.....	100	.93	18.50	46.25	B	
Mar. 12.....	100	.93	17.50	43.75	C	43.85
Mar. 13.....	100	.93	17.62	44.05	C	
Do.....	100	.93	17.50	43.75	C	

$P=1.911A+0.5B-1.411C=58.01$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=0.97$. $W=100$ grams.
 $M=\frac{VPS}{W}=8,440$ kilograms per square centimeter (120,037 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 28, 1909.

	Grams.
Solid.....	2.9
Liquid (water).....	80.5
Gaseous.....	110.1

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 75 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>° C.</i>	<i>Calories.</i>
Mar. 9.....	82.45	0.920	1,141.6
Mar. 10.....	82.05	.936	1,156.7
Do.....	81.85	.903	1,113.1

Average large calories per kilogram of explosive, 1,137.1.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 2.....	64.0	54.8	9.2
Do.....	64.0	54.0	10.0
Do.....	64.0	54.8	9.2

Average compression, 9.5 millimeters (0.37 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>° C.</i>
Oct. 16.....	62	375	313	15
Do.....	62	364	302	15
Do.....	62	370	308	15

Average expansion of bore hole, 308 cubic centimeters (18.79 cubic inches).

CHAPTER VI.

RESULTS OF TESTS WITH DYNAMITE.

By CLARENCE HALL and S. P. HOWELL.

PITTSBURGH TESTING STATION STANDARD DYNAMITE.

Explosive, Pittsburgh Testing Station standard dynamite.

Class, nitroglycerin.

Physical examination:

Diameter of cartridge, $1\frac{1}{4}$ inches.

Length of cartridge, 8 inches.

Average weight, 229 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 1.22.

Color of explosive, café-au-lait.

Consistency, fibrous and cohesive.

Determination of unit swing by ballistic pendulum:

Charge, 227 grams—

Date, November 26, 1909—

Swing, in inches, 2.92, 2.97, 2.85.

Average swing, in inches, 2.91.

Date, January 25, 1909—

Swing, in inches, 3.095, 2.940, 2.995.

Average swing, in inches, 3.01.

Date, April 5, 1909—

Swing, in inches, 2.865, 2.730, 2.805.

Average swing in inches, 2.80.

Date, April 30, 1909—

Swing, in inches, 2.70, 2.82, 2.80.

Average swing, in inches, 2.77.

Date, May 10, 1909—

Swing, in inches, 2.92, 2.88, 2.78.

Average swing, in inches, 2.86.

FORMULA OF DYNAMITE.

Nitroglycerin	40
Nitrate of soda (sodium nitrate)	44
Wood pulp	15
Carbonate of lime (calcium carbonate)	1

100

GAS AND DUST GALLERY. No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 4.	Grams.	Per cent.	
Oct. 27.....	100	4.08	Ignition.
Do.....	50	4.08	Do.
Do.....	25	4.08	Do.

Limit charge established at 0 gram.

During the period covered by this report many tests were run with 40 per cent nitroglycerin dynamite of the grade herein reported and other grades, and in every case ignition resulted whether the explosive was fired into gas and air, dust and air, or gas, dust, and air.

RATE OF DETONATION.

Diameter of cartridge, 1½ inches.

Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	<i>Millimeters.</i>	<i>Meters.</i>	<i>Meters.</i>
Mar. 6.....	9.357	43.5	4.649
Do.....	9.200	43.5	4.728

Average rate of detonation, 4,688 meters (15,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Oct. 28.....	19.50	24.63	7.00	0.350
Do.....	17.50	22.11	6.50	.325
Do.....	21.50	27.16	8.00	.400

Average height of flame, 24.63 inches.

Average duration of flame, 0.358 milliseconds.

IMPACT TEST.

Date, January 22, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
<i>Centimeters.</i>			<i>Centimeters.</i>		
11	2	No explosion.	10	5	No explosion.
11	1	Explosion.			

The maximum height at which no explosion occurs is established at 10 centimeters (3.94 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 196 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	<i>Inches.</i>			<i>Inches.</i>	
Nov. 15.....	13	Exploded.	Nov. 16.....	16	Did not explode.
Do.....	14	Did not explode.	Do.....	16	Exploded.
Do.....	14	Exploded.	Do.....	17	Did not explode.
Do.....	14	Do.	Do.....	17	Do.
Nov. 16.....	15	Do.	Do.....	17	Do.

The minimum distance at which no explosion occurs is established at 17 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME, AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter=1 kilogram per square centimeter.

Date (1908).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Dec. 16.....	100	1.24	21.50	38.39	A	38.09
Do.....	100	1.24	21.50	38.39	A	
Do.....	100	1.24	21.00	37.50	A	
Mar. 1, 1909.....	100	1.18	18.50	33.03	B	33.03
Do.....	100	1.18	18.00	32.14	B	
Do.....	100	1.24	19.00	33.93	B	
Do.....	100	1.24	17.75	31.69	C	31.40
Do.....	100	1.18	17.50	31.25	C	
Mar. 2.....	100	1.24	17.50	31.25	C	

$P=1.911A+0.58B-1.411C=45.00$ kilograms per square centimeter.
 $V=15,000$ cubic centimeters. $S=1.28$ $W=100$ grams.
 $M=\frac{VPS}{W}=8,235$ kilograms per square centimeter (117,121 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 22, 1909.

	<i>Grams.</i>
Solid.....	79.7
Liquid (water).....	14.5
Gaseous.....	88.4

GASEOUS PRODUCTS OF COMBUSTION.

	<i>Per cent. by volume.</i>
Carbon dioxide.....	51.4
Carbon monoxide.....	5.0
Hydrogen.....	2.2
Methane.....	.3
Nitrogen.....	41.1
	100.0

SOLID PRODUCTS OF COMBUSTION.

	<i>Per cent.</i>
Soluble (sodium carbonate).....	79.43
Insoluble (calcium carbonate, trace of unburned carbonaceous matter, and carbonates and oxides of copper, iron, and tin).....	20.57
	100.00

GASEOUS PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE AND 12.4 GRAMS OF PAPER WRAPPER.

[A. L. Hyde, analyst.]

	<i>Per cent.</i>
Carbon dioxide.....	27.3
Carbon monoxide.....	26.9
Hydrogen.....	18.0
Methane.....	.4
Nitrogen.....	27.4
	100.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grains.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Mar. 2.....	81.95	1.319	1,216.3
Mar. 3.....	81.90	1.318	1,223.1
Do.....	81.75	1.322	1,221.8

Average large calories per kilogram of explosive, 1,221.4.

COMPRESSION OF SMALL LEAD BLOCKS.

Date (1909).	Weight of charge.	Height.		Compression.
		Before explosion.	After explosion.	
	<i>Grams.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
Feb. 24.....	100	64.0	(^a)	
Mar. 3.....	25	64.0	48.0	16.0

^a Top of block shattered.

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>°C.</i>
Oct. 18.....	62	337	275	15
Do.....	62	344	282	15
Do.....	62	338	276	15

Average expansion of bore hole, 278 cubic centimeters (16.96 cubic inches).

58734°—Bull. 15—12—12

CHAPTER VII.

RESULTS OF TESTS WITH BLACK BLASTING POWDER.

By CLARENCE HALL and S. P. HOWELL.

FFF BLACK BLASTING POWDER

Explosive, FFF black blasting powder.

Class, black powder.

Apparent specific gravity of prepared cartridge by sand, 1.25.

Color, black.

Consistency, granular.

Unit defective charge, using 1 pound of tamping, as determined by the ballistic pendulum:

Date, November 26, 1909.

Unit swing on this date, 2.91 inches.

Weight of charge, in grams, 460, 460, 460.

Swing, in inches, 2.87, 2.90, 3.00.

Average swing, in inches, 2.92.

$$2.92 : 2.91 :: 460 : (458).$$

Therefore the unit defective charge of FFF black blasting powder, using 1 pound of tamping, is 458 grams.

Unit defective charge, using 2 pounds of tamping, as determined by the ballistic pendulum:

Date, February 25, 26, 27, 1909.

Unit swing on these dates, 3.01 inches.

Weight of charge, in grams, 375, 375, 375.

Swing, in inches, 3.03, 3.03, 3.00.

Average swing, in inches, 3.02.

$$3.02 : 3.01 :: 3.75 : (374).$$

Therefore the unit defective charge of FFF black blasting powder, using 2 pounds of tamping, is 374 grams.

During the period covered by this bulletin many tests were run with various grades of black blasting powder and in every case an ignition resulted, whether the shot was made into gas and air, dust and air, or gas, dust, and air.

RATE OF BURNING.

Electric igniter used

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of burning per second.
Apr. 22.	<i>Millimeters.</i> 53.26	<i>Meters.</i> 25	<i>Meters.</i> 469.4

Rate of burning 469.4 meters (1,540 feet) per second. This test was made with an FF black blasting powder.

FLAME TEST.

Peripheral speed of film, 0.40 meter per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	<i>Millimeters.</i>	<i>Inches.</i>	<i>Millimeters.</i>	<i>Milliseconds.</i>
Mar. 3.....	43.0	54.32	370.00	925.000

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centi- meter.
	<i>Grams.</i>		<i>Millimeters.</i>	<i>Kilograms.</i>		<i>Kilograms.</i>
Jan. 8.....	200	1.34	25.50	45.54	A	45.42
Jan. 13.....	200	1.21	25.50	45.54	A	
Do.....	200	1.22	25.50	45.54	A	
Do.....	200	1.21	25.25	45.02	A	
Mar. 18.....	200	1.33	22.50	40.18	B	41.63
Mar. 19.....	200	1.35	23.25	41.52	B	
Mar. 23.....	200	1.41	23.50	41.96	B	
Do.....	200	1.42	24.00	42.86	B	
Mar. 19.....	200	1.52	22.00	39.29	C	39.85
Do.....	200	1.47	22.00	39.29	C	
Mar. 20.....	200	1.41	22.75	40.63	C	
Do.....	200	1.44	22.50	40.18	C	

 $P = 1.911 A + 0.5B - 1.411 C = 51.38$ kilograms per square centimeter. $V = 15,000$ cubic centimeters. $S = 1.25$. $W = 200$ grams. $M = \frac{VPS}{W} = 4,817$ kilograms per square centimeter (68,509 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 300 GRAMS OF THE EXPLOSIVE.

Date, March 16, 1909.

	Grams.
Solid.....	126.9
Liquid (water).....	4.1
Gaseous.....	154.4

GASEOUS PRODUCTS OF COMBUSTION.

	Per cent by volume.
Carbon dioxide.....	49.7
Carbon monoxide.....	10.8
Hydrogen sulphide.....	8.7
Hydrogen.....	1.8
Methane.....	.6
Nitrogen.....	28.4
	100.0

SOLID PRODUCTS OF COMBUSTION.

	Per cent.
Soluble (sodium carbonate and sulphide with small amounts of sulphate and sulphite).....	91.2
Insoluble (carbon and sulphur in combination with iron and copper).....	8.8
	100.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 200 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	<i>Kilograms.</i>	<i>°C.</i>	<i>Calories.</i>
Apr. 1.....	82. 77	1. 640	769. 1
Apr. 2.....	82. 11	1. 738	809. 6

Average large calories per kilogram of explosive, 789.4.

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>°C.</i>
Dec. 6.....	62	90	28	15
Do.....	62	91	29	15
Do.....	62	92	30	15

Average expansion of bore hole, 29 cubic centimeters.

The average expansion of bore hole from three tests made December 6, 1909, with No. 7 electric detonators, gave 5 cubic centimeters. The detonators were placed in a cartridge of sand and then tamped in the usual manner.

CHAPTER VIII.

RESULTS OF TESTS OF FOUR FOREIGN EXPLOSIVES.

By CLARENCE HALL and S. P. HOWELL.

After the apparatus for testing explosives had been installed at the Pittsburgh testing station, comparative tests were made with the different classes of so-called safety powders then on the market. The results of these tests indicated that several of the explosives would pass the gallery tests when the charge was stemmed, but the highest limit charge established with unstemmed shots when fired in the presence of a mixture of gas and air containing 8 per cent of gas (methane and ethane) was only 100 grams. Repeated tests demonstrated that this limit charge could not be increased, even when loaded under special charging densities.

One of the explosives tested was similar in composition to a foreign "permitted" explosive of the nitroglycerin class, which was said to have a limit charge of 900 grams. Through the courtesy of one of the foreign testing stations, samples of this permitted explosive and of three other foreign permitted explosives were procured for comparative tests. The following chapter gives in detail the results of tests of these four explosives. Owing to the short time allotted, several of the tests were modified as to the number of trials; otherwise tests were conducted and methods were followed under approximately the same procedure as that of the foreign stations. It is to be noted that the highest limit charge established with the foreign explosives was only 50 grams. It was found after repeated tests that the limit charge could not be increased, even when loaded under special charging densities.

The results of tests indicated that all of the foreign explosives would pass the British tests, but would probably fail to pass the Continental tests. Only one of the explosives submitted, namely, explosive "D," would pass the test requirements requisite for its being placed in the United States permissible list.

The conclusions drawn were that the natural gas used at the Pittsburgh testing station was more sensitive than the pit gas used abroad, and that for this reason the percentage of gas used at Pittsburgh would necessarily have to be reduced in order to obtain results comparable with those obtained abroad.

For convenience in reporting the results of tests the four foreign explosives are here designated explosives A, B, C, and D.

Explosive A.

Class, black powder.

Physical examination:

Diameter of cartridge, 3.9 centimeters (1.5 inches).

Length of cartridge, 5.8 centimeters (2.25 inches).

Average weight, 92 grams.

The compressed pellet had been dipped.

Apparent specific gravity of cartridge by sand, 1.36.

Color of explosive, black and white, speckled.

Consistency, compressed pellet.

Explosive B.

Class, ammonium nitrate.

Physical examination:

Diameter of cartridge, 4.0 centimeters (1.5 inches).

Length of cartridge, 9.5 centimeters (3.65 inches).

Average weight, 116 grams.

Cartridge had been redipped.

Apparent specific gravity of cartridge by sand, 0.79.

Color of explosive, yellow.

Consistency, granular.

Explosive C.

Class, ammonium nitrate, containing nitroglycerin.

Physical examination:

Diameter of cartridge, 4.2 centimeters (1.67 inches).

Length of cartridge, 8.0 centimeters (3.25 inches).

Average weight, 113.5 grams.

Cartridge had been redipped.

Apparent specific gravity of cartridge by sand, 0.95.

Color of explosive, buff.

Consistency, dry, fibrous.

Explosive D.

Class, nitroglycerin.

Physical examination:

Diameter of cartridge, 4.0 centimeters (1.5 inches).

Length of cartridge, 19.0 centimeters (7.5 inches).

Average weight, 188 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.68.

Color of explosive, straw.

Consistency, fine, fibrous.

CHEMICAL ANALYSES.

Chemical analyses of these four explosives resulted as follows:

EXPLOSIVE A.	
Moisture.....	0. 46
Potassium nitrate.....	65. 31
Sulphur.....	2. 63
Charcoal.....	19. 52
Paraffin.....	3. 35
Starch.....	8. 73
Ash 0.97.	100. 00

EXPLOSIVE B.

Moisture.....	0. 17
Ammonium nitrate.....	89. 08
Trinitro-toluene.....	6. 56
Mononitro-naphthalene.....	4. 19
	100. 00

EXPLOSIVE C.

Moisture.....	0. 60
Nitroglycerin.....	8. 37
Ammonium nitrate.....	83. 14
Wood pulp.....	4. 65
Nitrotoluol.....	3. 24
	100. 00

Ash 0.098.

EXPLOSIVE D.

Moisture.....	4. 05
Nitroglycerin.....	24. 92
Barium nitrate.....	4. 42
Wood pulp.....	34. 60
Potassium nitrate.....	25. 37
Starch.....	6. 64
	100. 00

Ash 0.14.

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EACH EXPLOSIVE (WITHOUT PAPER WRAPPER).

Explosives.	Date (1909).	Test No.	Products of combustion.		
			Gaseous.	Solid.	Liquid (water).
			<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>
A.....	June 1	P 200	81.4	118.3	1.6
B.....	Apr. 28	P 147	111.9	.0	84.2
C.....	May 1	P 153	111.8	0.0	85.7
D.....	May 12	P 171	130.3	49.0	12.4

GASEOUS PRODUCTS OF COMBUSTION, PERCENTAGE BY VOLUME.

Explosives.	Date (1909).	Test No.	Products.						
			H ₂ S.	CO ₂ .	CO.	O ₂ .	H ₂ .	CH ₄ .	N ₂ .
			<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
A.....	June 1	P 200	1.1	13.9	41.8	.0	23.6	2.8	16.8
B.....	Apr. 28	P 147	.0	26.7	.0	3.2	.0	0	70.1
C.....	May 1	P 153	.0	30.8	.0	1.5	.0	0	67.7
D.....	May 12	P 171	.0	18.9	36.3	.0	29.1	5.8	9.9

SOLID PRODUCTS OF COMBUSTION, PERCENTAGE BY WEIGHT.

Explosives.	Date (1909).	Test No.	Products of combustion.	
			Soluble.	Insoluble.
A.....	June 1	P 200	87.84	12.16
D.....	May 12	P 171	76.10	23.90

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge A = 200 grams; B, C, and D = 100 grams.

Explosives.	Date (1909).	Test No.	Weight of water.	Rise in tempera- ture.	Heat de- veloped per kilo- gram.	Average heat de- veloped per kilo- gram.
			<i>Kilos.</i>	<i>° C.</i>	<i>Calories.</i>	<i>Calories.</i>
A.....	Sept. 3	106	81.90	1.342	623	622.7
		107	81.70	1.315	609	
		108	81.60	1.375	636	
B.....	June 3	79	82.73	1.290	1,208	1,197.0
		80	82.73	1.294	1,211	
		81	82.73	1.252	1,172	
C.....	Sept. 9	112	81.60	1.345	1,244	1,245.0
		113	82.25	1.328	1,237	
		114	83.35	1.330	1,254	
D.....	Sept. 8	110	81.70	.626	575	570.7
		111	81.75	.617	567	
		115	81.95	.619	570	

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Explosives. ^a	Date (1909).	Test No.	Height before explosion.	Height after explosion.	Compression.
			<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Millimeters.</i>
B.....	Apr. 22	B 111	63.7	55.5	8.2
		B 112	63.7	55.8	7.9
		B 113	63.7	56.0	7.7
C.....	22	B 114	63.5	46.5	17.0
		B 115	63.5	47.0	16.5
		B 116	63.5	46.5	17.0
D.....	22	B 117	63.0	53.0	10.0
		B 118	63.0	52.8	10.2
		B 119	63.0	53.0	10.0

^a This test was not run on explosive A, as it was a slow-burning explosive.

The average compression is as follows:

Explosive B, 7.93 millimeters (0.31 inch).

Explosive C, 16.83 millimeters (0.66 inch).

Explosive D, 10.07 millimeters (0.40 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Explosives. ^a	Date (1909).	Test No.	Volume of bore hole before shot.	Volume of bore hole after shot.	Expansion of bore hole.
			<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>	<i>Cubic centimeters.</i>
B.....	Apr. 5	A 154	62	280	218
		A 155	62	287	225
		A 156	62	287	225
C.....	5	A 157	62	340	278
		A 158	62	372	310
		A 159	62	378	316
D.....	5	A 160	62	214	152
		A 161	62	228	166
		A 162	62	212	150

^a This test was not made with explosive A, as it was slow burning.

The average expansions follow:

Explosive B, 223 cubic centimeters (13.60 cubic inches).

Explosive C, 301 cubic centimeters (18.36 cubic inches).

Explosive D, 156 cubic centimeters (9.52 cubic inches).

BALLISTIC-PENDULUM TESTS.

The standard Woolwich swing was taken as the swing produced by 295 grams (10½ ounces) of explosive A, tamped with 2 pounds of dry fire clay. The standard (Woolwich) swing of explosive A and the computed swings of explosives B, C, and D follow:

SWINGS OF EXPLOSIVES A, B, C, AND D.

Explosives.	Date (1909).	Charge.	Swing.	Average swing.	Woolwich disruptive charge.
		<i>Grams.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Grams.</i>
A.....	Mar. 29	295	1.71	1.68	295
	29	295	1.61		
	29	295	1.73		
B.....	29	140	1.62	1.63	144
	29	140	1.62		
	29	140	1.64		
C.....	29	110	1.38	1.35	137
	29	110	1.35		
	29	110	1.33		
D.....	30	200	1.72	1.69	199
	30	200	1.63		
	30	200	1.71		

NOTE.—Swing figures for explosive A are results of tests; swings of explosives B, C, and D computed.

UNIT DEFLECTIVE CHARGE AS DETERMINED BY THE BALLISTIC PENDULUM.

Explosives.	Date (1909).	Charge.	Swing.	Average swing.	Unit deflective charge.
		<i>Grams.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Grams.</i>
Pittsburgh testing station 40 per cent standard dynamite.....	Mar. 30	227	2.675	a 2.70	227
	30	227	2.675		
	30	227	2.765		
A.....	30	400	2.55	2.55	420
	30	400	2.58		
	30	400	2.51		
Pittsburgh testing station 40 per cent standard dynamite.....	31	227	2.70	2.76	227
	31	227	2.82		
	31	227	2.75		
B.....	31	205	2.70	2.76	205
	31	205	2.75		
	31	205	2.84		
C.....	31	195	2.65	2.67	202
	31	195	2.64		
	31	195	2.73		
D.....	31	295	2.77	2.73	298
	31	295	2.65		
	31	295	2.78		

a 2.68 was used in computing unit deflective charge for explosive A.

In all of the tests in gas and dust gallery No. 1 the following igniter and detonators were used:

- Explosive A, electric igniter.
- Explosive B, electric detonator No.7.
- Explosive C, electric detonator No. 6.
- Explosive D, electric detonator No. 6.

THE BELGIAN TEST (MODIFIED) FOR DETERMINATION OF THE LIMIT CHARGE IN A MIXTURE OF GAS AND AIR CONTAINING 8 PER CENT OF METHANE AND ETHANE.

Limit charge is established if five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Mar. 29	50	8.20	Ignition.
	29	25	8.18	Do.
	29	25	8.08	Do.
B.....	29	200	8.08	Do.
	29	50	8.02	No ignition.
	29	125	8.02	Ignition.
	29	100	7.87	Do.
	29	75	7.89	Do.
	29	50	7.83	Do.
	29	25	8.01	Do.
C.....	29	200	8.01	Do.
	29	100	7.82	Do.
	29	25	7.77	Do.
D.....	29	25	7.86	No ignition.
	29	100	7.89	Ignition.
	29	50	8.01	No ignition.
	29	75	8.08	Ignition.
	29	50	8.08	No ignition.
	29	50	8.13	Do.
	29	50	8.00	Do.
	29	50	8.11	Do.

The limit charges for this test are established as follows:

	<i>Grams.</i>
Explosive A.....	0
Explosive B.....	0
Explosive C.....	0
Explosive D.....	50

WOOLWICH TEST (MODIFIED).

Five shots with the standard (Woolwich) charge, in its original wrapper, shall be fired with 12 inches of clay tamping (explosive A hammered in; B, C, and D tamped by hand) at a gallery temperature of 77° F. into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive passes this test if all five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Mar. 30	295	7.92	No Ignition.
	30	295	8.03	Do.
	30	295	8.12	Do.
	30	295	7.95	Do.
	30	295	8.15	Do.
B.....	30	144	7.96	Do.
	30	144	7.96	Do.
	30	144	7.87	Do.
	30	144	7.87	Do.
	30	144	7.84	Do.
C.....	30	137	7.90	Do.
	30	137	7.86	Do.
	30	137	7.86	Do.
	30	137	7.96	Do.
	30	137	7.81	Do.
D.....	30	199	7.98	Do.
	30	199	8.15	Do.
	30	199	8.15	Do.
	30	199	8.16	Do.
	30	199	8.18	Do.

The explosives A, B, C, and D passed this test.

WOOLWICH TEST (MODIFIED).

Five shots with three-quarters of the standard (Woolwich) charge, in its original wrapper, shall be fired with 9 inches of clay tamping (explosive A hammered in; B, C, and D by hand) at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive passes this test if all five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Mar. 30	221	8.13	No ignition.
	30	221	8.13	Do.
	30	221	8.13	Do.
	30	221	8.18	Do.
	30	221	8.11	Do.
B.....	30	108	7.86	Do.
	30	108	7.84	Do.
	30	108	7.86	Do.
	30	^a 144	7.76	Do.
	30	108	7.92	Do.
C.....	30	103	8.71	Do.
	30	103	8.18	Do.
	31	103	8.24	Do.
	31	103	8.24	Do.
	31	103	8.23	Do.
D.....	31	150	8.12	Do.
	31	150	8.25	Do.
	31	150	8.25	Do.
	31	150	8.25	Do.
	31	150	8.12	Do.

^a Weight of charge was greater than unit disruptive charge.

The explosives A, B, C, and D passed this test.

BUREAU OF MINES TESTS.

GAS AND DUST GALLERY No. 1.

Test 1, except that 5 shots are made instead of 10.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Apr. 20	420	8.05	Ignition. ^a
B.....	3	205	8.27	No ignition.
	3	205	8.11	Do.
	3	205	8.34	Do.
	3	205	8.33	Do.
	3	205	8.00	Do.
C.....	4	202	7.78	Do.
	4	202	8.12	Ignition.
	4	202	8.12	No ignition.
	24	202	8.12	Do.
	24	202	7.84	Ignition.
D.....	24	298	8.01	No ignition.
	24	298	7.89	Do.
	24	298	7.89	Do.
	24	298	7.89	Do.
	24	298	7.78	Do.

^a Bore reduced to $1\frac{1}{2}$ inches for this test by using a $1\frac{1}{2}$ -inch inside diameter pipe in bore hole.

Explosives B and D passed this test.

Explosives A and C failed to pass this test.

GAS AND DUST GALLERY No. 1.

Same as test 2, except that 5 shots are made instead of 10.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Apr. 4	420	4.06	No ignition.
	4	420	3.98	Do.
	4	420	4.06	Do.
	4	420	3.98	Do.
	4	420	4.06	Do.
B.....	3	205	4.06	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
C.....	3	202	4.06	Do.
	3	202	3.98	Do.
	3	202	3.98	Do.
	3	202	4.06	Do.
	3	202	4.06	Do.
D.....	3	298	3.98	Do.
	3	298	3.98	Do.
	3	298	4.06	Do.
	3	298	3.89	Do.
	3	298	3.89	Do.

The explosives A, B, C, and D passed this test.

GAS AND DUST GALLERY No. 1.

Same as test 3, except that 5 shots are used instead of 10.

Explosives.	Date (1909).	Weight of charge.	Result.
		<i>Grams.</i>	
A.....	Apr. 2	420	No ignition.
	2	420	Do.
	2	420	Do.
	2	420	Do.
	2	420	Do.
B.....	2	205	Do.
	2	205	Do.
	2	205	Do.
	2	205	Do.
	2	205	Do.
C.....	2	202	Do.
	2	202	Do.
	2	202	Do.
	2	202	Do.
	2	202	Do.
D.....	2	298	Do.
	2	298	Do.
	2	298	Do.
	2	298	Do.
	2	298	Do.

The explosives A, B, C, and D passed this test.

GAS AND DUST GALLERY No. 1.

Test 4.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Mar. 31	50	4.23	No ignition.
	31	100	4.11	Do.
	31	200	4.24	Ignition.
	31	200	(a)	
	31	150	4.19	Do.
	31	125	4.19	Do.
	31	100	4.04	No ignition.
	31	100	4.05	Do.
	31	100	4.21	Do.
	31	100	4.20	Do.
B.....	31	200	4.02	Do.
	31	300	4.02	Ignition.
	31	250	3.98	Do.
	31	225	4.19	No ignition.
	31	225	4.02	Ignition.
	31	200	4.02	Do.
	31	175	4.02	Do.
	31	175	4.04	Do.
	31	150	4.13	No ignition.
	31	150	4.13	Do.
	31	150	4.05	Ignition.
	31	125	3.96	Do.
	31	100	4.02	Do.
	31	75	4.11	No ignition.
	31	75	4.02	Do.
	Apr. 1	75	4.02	Do.
	1	75	4.11	Do.
	1	75	4.11	Do.

a No gas or dust used, in order to note effect of charge alone. Flame in no doorway, but in window No. 1.

GAS AND DUST GALLERY No. 1—Continued.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
C.....	Apr. 1	200	4.11	Ignition.
	1	100	4.11	Do.
	1	50	4.18	No ignition.
	1	75	4.14	Do.
	1	75	3.98	Do.
	1	75	4.11	Do.
	1	75	4.07	Do.
	1	75	4.07	Do.
D.....	1	100	4.07	Do.
	1	200	4.14	Do.
	1	300	4.07	Do.
	1	500	4.07	Do.
	1	700	4.14	Do.
	4	1,000	4.07	Do.
	21	1,000	3.96	Do.
	21	1,000	4.07	Do.
	21	1,000	3.96	Do.
	21	1,000	4.05	Do.

For this test the following limit charges were established:

	Grams.
Explosive A.....	100
Explosive B.....	75
Explosive C.....	75
Explosive D (the capacity of the cannon).....	1,000

GAS AND DUST GALLERY No. 1.

Test 5.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
A.....	Apr. 1	200	2.03	No ignition.
	1	300	1.96	Do.
	1	400	2.20	Do.
	6	600	2.68	Ignition.
	6	500	2.03	Do.
	6	450	2.03	Do.
	6	425	2.03	Do.
	6	400	2.04	Do.
	6	375	2.04	Do.
	6	350	2.04	Do.
	6	300	2.03	No ignition.
	6	325	2.03	Ignition.
	14	300	2.26	Do.
	14	250	2.26	No ignition.
	14	275	2.46	Do.
	15	275	2.17	Do.
	15	275	2.26	Do.
	15	275	2.27	Do.
	15	275	2.26	Do.
B.....	4	200	2.21	Do.
	4	300	2.29	Do.
	4	400	2.29	Ignition.
	4	350	2.21	Do.
	4	325	2.10	No ignition.
	4	325	2.03	Ignition.
	4	300	2.03	Do.
	4	275	2.04	Do.
	4	250	2.03	No ignition.
	4	250	2.03	Do.
	4	250	2.03	Do.
	4	250	2.05	Do.
	4	250	2.03	Do.

GAS AND DUST GALLERY No. 1—Continued.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		<i>Grams.</i>	<i>Per cent.</i>	
C.....	Apr. 1	400	2.03	Ignition.
	1	200	2.04	No ignition.
	1	300	2.03	Do.
	2	350	1.97	Do.
	2	375	2.11	Ignition.
	2	350	2.11	No ignition.
	2	350	2.03	Do.
	2	350	2.03	Ignition.
	2	325	2.05	No ignition.
	2	325	2.03	Ignition.
	2	300	2.04	Do.
	2	275	2.04	No ignition.
	2	275	2.03	Do.
	2	275	2.13	Do.
	2	275	2.11	Do.
	2	275	2.03	Do.
D.....	4	1,000	2.03	Do.

For this test the following limit charges were established:

	Grams.
Explosive A.....	275
Explosive B.....	250
Explosive C.....	275
Explosive D (the capacity of the cannon).....	1,000

RATE OF DETONATION.

Diameter of cartridge used, $1\frac{1}{4}$ inches.

Electric detonator No. 7 used.

Explosives.	Date (1909).	Distance between spark points.	Peripheral speed of of drum.	Rate of detonation.
		<i>Millimeters.</i>	<i>Meters per second.</i>	<i>Meters per second.</i>
A.....		Rate of burning too slow to give interruption sparks.		
B.....	May 6	14.70	43	2,925
	7	14.71	43	2,923
C.....	5	11.26	43	3,819
	6	11.09	43	3,877
D.....	7	17.06	43	2,520
	7	16.18	43	2,658

The average rates of detonations of the explosives are as follows:

Explosive B, 2,924 meters per second (9,590 feet per second).

Explosive C, 3,848 meters per second (12,620 feet per second).

Explosive D, 2,589 meters per second (8,490 feet per second).

FLAME TEST.

Peripheral speed of film $\frac{5}{16}$ meter per second for explosive A; 20 meters per second for explosives B, C, and D.

Explosives.	Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
		<i>Milli- meters.</i>	<i>Inches.</i>	<i>Milli- meters.</i>	<i>Milli- seconds.</i>
A.....	May 17	48.00	60.63	322.00	1,030.400
B.....	3	23.50	29.68	12.25	.612
	3	22.25	28.11	10.25	.512
	3	23.25	29.37	13.00	.650
C.....	Apr. 28	21.50	27.16	8.50	.425
	28	21.25	26.84	8.25	.412
	28	21.50	27.16	7.50	.375
D.....	28	15.00	18.95	6.75	.338
	28	15.00	18.95	7.75	.388
	28	15.75	19.89	6.75	.338

The average heights and durations of flame are as follows:

Explosive A, height 60.63 inches; duration 1030.400 milliseconds.

Explosive B, height 29.05 inches; duration .591 milliseconds.

Explosive C, height 27.05 inches; duration .404 milliseconds.

Explosive D, height 19.26 inches; duration .355 milliseconds.

IMPACT MACHINE.

Explosives.	Date (1909).	Distance of fall.	Number of falls.	Result.
		<i>Centi- meters.</i>		
A.....	Sept. 7	60	1	No explosion.
	7	80	1	Do.
	7	90	1	Do.
	7	100	5	Do.
B.....	8	42	1	Do.
	8	50	1	Do.
	8	60	1	Do.
	8	70	1	Do.
	8	80	1	Do.
	8	90	1	Do.
	8	100	5	Do.
C.....	8	34	1	Explosion.
	8	32	1	Do.
	8	31	1	No explosion.
	8	31	1	Explosion.
	8	30	5	No explosion.
D.....	24	50	1	Explosion.
	24	45	1	Do.
	24	40	1	Do.
	24	35	1	Do.
	24	30	1	Do.
	24	25	1	Do.
	24	20	1	Do.
	24	15	1	Do.
	24	10	1	No explosion.
	24	14	1	Explosion.
	24	13	5	No explosion.

The maximum heights that will cause no explosion are established as follows:

Explosive A, 100 centimeters (39.37 inches), capacity of machine.

Explosive B, 100 centimeters (39.37 inches), capacity of machine.

Explosive C, 30 centimeters (11.81 inches).

Explosive D, 13 centimeters (5.12 inches).

EXPLOSION BY INFLUENCE TEST

Explosives, ^a	Date (1909).	Weight of cartridge.	Distance separating cartridges.	Result (upper car- tridge).
		<i>Grams.</i>	<i>Inches.</i>	
B.....	June 2	155	2	No explosion.
	2	155	1	Do.
	3	155	$\frac{1}{2}$	Do.
	Sept. 8	155	$\frac{1}{2}$	Partial explosion.
	9	155	$\frac{1}{2}$	
	9	155	$\frac{1}{2}$	No explosion.
	13	155	$\frac{1}{2}$	Do.
C.....	9	153	2	Explosion.
	24	153	4	No explosion.
	24	153	3	Do.
	24	153	2	Explosion.
	24	153	3	No explosion.
	24	153	3	Do.
D.....	4	90	6	Do.
	4	90	3	Explosion.
	7	90	5	No explosion.
	7	90	4	Do.
	7	90	4	Do.
	7	90	4	Do.
	7	90	4	Do.

^a This test was not run with explosive A, as it was impracticable to make it under standard-size cartridges.

The minimum distances at which there was no explosion by influence are established as follows:

	<i>Inches.</i>
Explosive B.....	0
Explosive C.....	3
Explosive D.....	4

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter = 1 kilogram per square centimeter.

Special conditions for explosive A; the initial pressure was 1 atmosphere, and electric igniters were used.

Explosives.	Date (1909).	Test No.	Charge.	Specific gravity.	Height of curve.	Pressure.	Cooling surface.	Average pressure.
			<i>Grams.</i>		<i>Milli- meters.</i>	<i>Kilograms per square centimeter.</i>		<i>Kilograms per square centimeter.</i>
A.....	May	22 P 189	300	1.38	26.00	65.00	A	64.17
		22 P 190	300	1.38	25.50	63.75	A	
		22 P 191	300	1.38	25.50	63.75	A	
		22 PP 199	300	1.38	24.00	60.00	B	
		22 PP 200	300	1.38	24.75	61.88	B	61.25
		22 PP 201	300	1.38	24.75	61.88	B	
		24 PP 202	300	1.38	24.50	61.25	C	
		24 PP 203	300	1.38	24.80	62.00	C	
		24 PP 204	300	1.38	25.25	63.13	C	62.13
		17 P 176	200	.88	44.25	110.63	A	
B.....		17 P 178	200	.88	43.00	107.50	A	107.92
		17 P 179	200	.88	42.25	105.63	A	
		13 PP 181	200	.92	40.00	100.00	B	
		13 PP 182	200	.88	40.00	100.00	B	
		14 PP 183	200	.88	39.50	98.75	B	99.58
		14 PP 184	200	.88	38.25	95.63	C	
		15 PP 185	200	.88	38.00	95.00	C	
		17 PP 186	200	.88	39.50	98.75	C	

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED
BY BICHEL PRESSURE GAGE—Continued.

Explosives.	Date (1909).	Test No.	Charge.	Specific gravity.	Height of curve.	Pressure.	Cooling surface.	Average pressure.	
			Grams.		Milli- meters.	Kilograms per square centimeter.		Kilograms per square centimeter.	
C.....	May	18	P 180	200	.96	41.25	103.13	A	103.13
		18	P 181	200	.96	41.25	103.13	A	
		18	P 182	200	.96	41.25	103.13	A	
		19	PP 190	200	.96	38.25	95.63	B	94.38
		19	PP 191	200	.96	38.00	95.00	B	
		19	PP 192	200	.96	37.00	92.50	B	
		18	PP 187	200	.96	36.00	90.00	C	90.63
		18	PP 188	200	.96	36.50	91.25	C	
		19	PP 189	200	.96	36.25	90.63	C	
D.....		21	P 186	200	.76	24.50	61.25	A	61.33
		21	P 187	200	.76	24.60	61.50	A	
		21	P 188	200	.76	24.50	61.25	A	
		20	PP 193	200	.76	23.50	58.75	B	58.33
		20	PP 194	200	.76	23.25	58.13	B	
		20	PP 195	200	.76	23.25	58.13	B	
		20	PP 196	200	.76	22.50	56.25	C	56.25
		20	PP 197	200	.76	22.50	56.25	C	
		20	PP 198	200	.76	22.50	56.25	C	

Computations for the respective explosives, established as the result of the above tests, were as follows:

Explosive A: $P=1.911A+0.5B-1.411C=65.59$ kilos. per square centimeter.
 $V=15,000$ cubic centimeters. $S=1.36$. $W=300$ grams. $M=\frac{VPS}{W}=4,460.12$ kilos
per square centimeter (63,440 pounds per square inch).

Explosive B: $P=1.911A+0.5B-1.411C=119.92$ kilos. per square centimeter.
 $V=15,000$ cubic centimeters. $S=0.79$. $W=200$ grams. $M=\frac{VPS}{W}=7,105.26$ kilos per
square centimeter (101,070 pounds per square inch).

Explosive C: $P=1.911A+0.5B-1.411C=116.39$ kilos. per square centimeter.
 $V=15,000$ cubic centimeters. $S=0.95$. $W=200$ grams. $M=\frac{VPS}{W}=8,292.79$ kilos
per square centimeter (117,960 pounds per square inch).

Explosive D: $P=1.911A+0.5B-1.411C=67.00$ kilos. per square centimeter.
 $V=15,000$ cubic centimeters. $S=0.68$. $W=200$ grams. $M=\frac{VPS}{W}=3,417.00$ kilos
per square centimeter (48,600 pounds per square inch).

APPENDIX.

BUREAU OF MINES TESTS OF EXPLOSIVES.

CONDITIONS UNDER WHICH EXPLOSIVES ARE TESTED.

The following conditions under which the Bureau of Mines tests explosives to determine whether they shall be placed on its list of permissible explosives were approved January 3, 1911:

1. The manufacturer is to deliver to the Bureau of Mines, Fortieth and Butler Streets, Pittsburgh, Pa., three weeks prior to the date set for tests, 100 pounds of each explosive that he desires to have tested. He is to be responsible for the care, handling, and delivery of this material to the testing station, and he is to have a representative present during the tests. In order to avoid duplication of work, it is requested that the smallest size of cartridge that the manufacturer intends to place on the market be sent for these tests.

2. The manufacturer will be required to pay fees for tests of explosives as outlined in schedule 1 of the Bureau of Mines. This schedule may be procured from the Director of the Bureau of Mines, Washington, D. C.

3. No one is to be present at or participate in these tests except the necessary Government officers at the experiment station, their assistants, and the representative of the manufacturer of the explosives to be tested.

4. The tests will be made in the order of the receipt of the applications for them, provided the necessary quantity of the explosive is delivered at the testing station by the date set, of which date due notice will be given by the Bureau of Mines.

5. A list of the explosives that pass certain requirements satisfactorily will be furnished to State mine inspectors and will be made public in such other manner as may be considered desirable.

6. The details of results of tests are to be considered confidential by the manufacturer and are not to be made public prior to official publication by the Bureau of Mines.

7. From time to time field samples of permissible explosives will be collected, and tests will be made of these explosives as they are supplied for use in coal mines in the various States.

TEST REQUIREMENTS FOR EXPLOSIVES.

The following test requirements for permissible explosives were approved on January 3, 1911:

The tests will be made by the engineers of the United States mining experiment station at Pittsburgh, Pa., in gas and dust gallery No. 1. The charge of explosive to be fired in tests 1, 2, and 3 shall be equal in deflective power, as determined by the ballistic pendulum, to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite in its original wrapper, of the following formula:

	Per cent.
Nitroglycerin.....	40
Nitrate of soda (sodium nitrate).....	44
Wood pulp.....	15
Carbonate of lime (calcium carbonate).....	1
	100

Each charge shall be fired with an electric detonator (exploder or cap) strong enough to completely detonate or explode the charge, as recommended by the manufacturer. The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results.

In order that the dust used in tests 3 and 4 may be of the same quality, it is always taken from the same mine, ground to the same fineness, and used while still fresh.

The following are the gallery tests to which are subjected the explosives that the Bureau of Mines is asked to place in the list of permissible explosives:

Test 1. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound ^a of clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of gas (methane and ethane). An explosive is considered to have passed the test if no one of the ten shots ignites this mixture.

Test 3. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound ^a of clay stemming, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 20 pounds of which is to be distributed uniformly on a wooden bench placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed the test if no one of the ten shots ignites this mixture.

Test 4. Five shots each with 1½-pound charge, in its original wrapper, shall be fired without stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of gas (methane and ethane) and 20 pounds of bituminous coal dust, 18 pounds of which is to be placed on shelves along the sides of the first 20 feet of the gallery and 2 pounds to be so placed that it will be stirred up by an air current in such manner that all or part of it will be suspended in the first division of the gallery. An explosive is considered to have passed the test if no one of the five shots ignites this mixture.

DEFINITION OF PERMISSIBLE EXPLOSIVE.

An explosive is called a permissible explosive when it is similar in all respects to the sample that passed certain tests by the national Bureau of Mines, and when it is used in accordance with the conditions prescribed by that bureau.

The tests now prescribed as those a permissible explosive must have passed are those given above. But even the explosives that have passed those tests and are published as permissible explosives are to be considered as permissible explosives only when used under the following conditions:

1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

2. That detonators—preferably electric detonators—are used of not less efficiency than those prescribed, namely, those consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or their equivalents).

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That the quantity used for a shot does not exceed 1½ pounds (680 grams), properly tamped with clay or other noncombustible stemming.

It must not be supposed that an explosive that has once passed the above-mentioned tests and has been published in lists of permissible explosives is thereafter to be considered a permissible explosive, regardless of its condition or the way in which it is used. Thus, for example, an explosive named in the permissible list, if kept in a moist place until it undergoes a change in character, is no longer to be considered

^a Two pounds of clay stemming are used with slow-burning explosives.

a permissible explosive. If used in a frozen or partly frozen condition, it is not when so used a permissible explosive. If used in excess of the quantity specified (1½ pounds), it is not when so used a permissible explosive. And when the other conditions have been met, it is not a permissible explosive if fired with a detonator of less efficiency than that prescribed.

Moreover, even when all the prescribed conditions have been met, no permissible explosive should necessarily be considered as *permanently* being a permissible explosive, but any permissible explosive when used under the prescribed conditions may properly continue to be considered a permissible explosive until notice of its withdrawal or removal from the list has been officially published or until its name is omitted from a later list published by the Bureau of Mines.

Furthermore, the manufacturers of a permissible explosive may withdraw it at any time when introducing a new explosive of superior qualities. And after further experiments and conferences the Bureau of Mines may find it advisable to adopt additional and more severe tests to which all permissible explosives may be subjected, in the hope that through the use of such explosives only as may pass the more severe tests the lives of miners may be better safeguarded.

Subject to the conditions and provisions stated above, the following explosives are classed as permissible explosives:

Permissible explosives tested prior to January 1, 1912.

Brand.	Class designation.	When used with detonators, preferably electric detonators, not less than—	Manufacturer.
Aetna coal powder A.....	Class 4.....	No. 6.....	Aetna Powder Co., Chicago, Ill.
Aetna coal powder AA.....	Class 1 a.....	do.....	Do.
Aetna coal powder B.....	Class 4.....	do.....	Do.
Aetna coal powder C.....	do.....	do.....	Do.
Bental coal powder No. 1-A.....	Class 1 a.....	do.....	Independent Powder Co. of Missouri, Joplin, Mo.
Bental coal powder No. 2.....	do.....	No. 7.....	Do.
Bituminite No. 1.....	Class 4.....	No. 6.....	Jefferson Powder Co., Birmingham, Ala.
Bituminite No. 3.....	do.....	do.....	Do.
Bituminite No. 4.....	do.....	do.....	Do.
Bituminite No. 5.....	Class 1 a.....	do.....	Do.
Bituminite No. 7.....	do.....	do.....	Do.
Cameron mine powder No. 1-A.....	do.....	do.....	Cameron Powder Manufacturing Co., Emporium, Pa.
Cameron mine powder No. 2-A.....	do.....	do.....	Do.
Cameron mine powder No. 2-A, L. F.....	do.....	do.....	Do.
Cameron mine powder No. 3-A.....	Class 4.....	do.....	Do.
Carbonite No. 1.....	do.....	do.....	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Carbonite No. 2.....	do.....	do.....	Do.
Carbonite No. 3.....	do.....	do.....	Do.
Carbonite No. 4.....	do.....	do.....	Do.
Carbonite No. 5.....	do.....	do.....	Do.
Carbonite No. 6.....	do.....	do.....	Do.
Coalite No. 1.....	do.....	do.....	Potts Powder Co., New York, N. Y.
Coalite No. 2-D.....	do.....	do.....	Do.
Coalite No. 2-D, L.....	do.....	do.....	Do.
Coalite No. 3-X.....	Class 1 a.....	do.....	Do.
Coalite No. 3-XA.....	do.....	do.....	Do.
Coalite No. 3-XB.....	do.....	do.....	Do.
Coal special No. 1.....	Class 4.....	do.....	Keystone National Powder Co., Emporium, Pa.
Coal special No. 2.....	do.....	do.....	Do.
Coal special No. 2-W.....	do.....	do.....	Do.
Coal special No. 3-C.....	do.....	do.....	Do.
Collier No. 9.....	Class 1 a.....	do.....	Do.
Collier powder No. 2.....	Class 4.....	do.....	Do.
Collier powder No. 5.....	Class 1 a.....	do.....	Do.
Collier powder No. 5-L, F.....	do.....	do.....	Do.
Collier powder No. 5 special.....	do.....	do.....	Do.
Collier powder No. 6-L, F.....	Class 4.....	do.....	Do.
Collier powder No. X.....	Class 1 a.....	do.....	Do.
Detonite special.....	do.....	No. 7.....	The King Powder Co., Cincinnati, Ohio.

Permissible explosives tested prior to January 1, 1912—Continued.

Brand.	Class designation.	When used with detonators, preferably electric detonators, not less than—	Manufacturer.
Fuel-ite No. 1.....	Class 4.....	No. 6.....	Burton Powder Co., Pittsburgh, Pa.
Fuel-ite No. 2.....	do.....	do.....	Do.
Fuel-ite No. 3.....	Class 1 a.....	do.....	Do.
Giant A low-flame dynamite.....	Class 2.....	do.....	Giant Powder Co. (Consolidated), Giant, Cal.
Giant B low-flame dynamite.....	do.....	do.....	Do.
Giant C low-flame dynamite.....	do.....	do.....	Do.
Giant coal-mine powder No. 5.....	Class 1 a.....	do.....	Do.
Giant coal-mine powder No. 6.....	Class 2.....	do.....	Do.
Giant coal-mine powder No. 7.....	do.....	do.....	Do.
Giant coal-mine powder No. 8.....	do.....	do.....	Do.
Guardian No. 2.....	Class 1 a.....	do.....	Independent Powder Co. of Mis- souri, Joplin, Mo.
Guardian No. 3.....	do.....	do.....	Do.
Hecla No. 2.....	do.....	No. 7.....	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Kanite A.....	Class 1 b.....	do.....	W. H. Blumenstein Chemical Works, Pottsville, Pa.
Meteor AXXO.....	Class 2.....	No. 6.....	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Mine-ite A.....	Class 4.....	do.....	Burton Powder Co., Pittsburgh, Pa.
Mine-ite B.....	do.....	do.....	Do.
Monobel No. 1.....	Class 1 a.....	do.....	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Monobel No. 2.....	do.....	do.....	Do.
Monobel No. 3.....	do.....	do.....	Do.
Monobel No. 4.....	do.....	do.....	Do.
Monobel No. 5.....	do.....	do.....	Do.
Nitro low-flame No. 1.....	Class 4.....	do.....	Nitro Powder Co., Kingston, N. Y.
Nitro low-flame No. 2.....	do.....	do.....	Do.
Polar C.....	Class 1 a.....	No. 8.....	Potts Powder Co., New York, N. Y.
Titanite No. 3-P.....	do.....	No. 6.....	Waclark Titanite Explosive Co., Corry, Pa.
Titanite No. 4-P.....	do.....	No. 7.....	Do.
Titanite No. 7-P.....	do.....	do.....	Do.
Trojan coal powder H.....	Class 3.....	No. 6.....	Pennsylvania Trojan Powder Co., Allentown, Pa.
Trojan coal powder I.....	do.....	do.....	Do.
Trojan coal powder J.....	do.....	do.....	Do.
Tunnelite No. 5.....	Class 4.....	do.....	G. R. McAbee Powder & Oil Co., Pittsburgh, Pa.
Tunnelite No. 6.....	do.....	do.....	Do.
Tunnelite No. 6-L. F.....	do.....	do.....	Do.
Tunnelite No. 7.....	do.....	do.....	Do.
Tunnelite No. 8.....	do.....	do.....	Do.
Tunnelite No. 8-L. F.....	do.....	do.....	Do.
Zero No. 3.....	Class 1 a.....	No. 7.....	Burton Powder Co., Pittsburgh, Pa.

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PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1911. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1911. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine explosions and fires, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives. 1912.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 27. Monthly statistics of coal-mine accidents in the United States, January to August, 1912; and statistics for 1910 and 1911, compiled by F. W. Horton. 1912. 24 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be observed in their use, by Clarence Hall. 1912. 20 pp.

